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The use of PFAS and fluorine-free alternatives in fire-fighting foams

Final report

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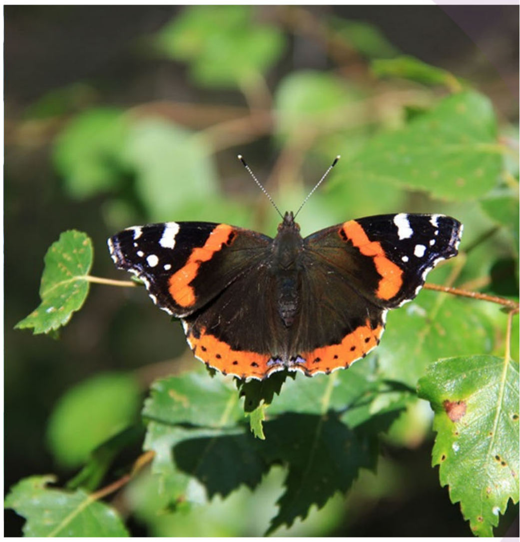

Wood Environment and Infrastructure Solutions – June 2020

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Report for

Valentina Bertato
Policy Officer
European Commission – Directorate General Environment
Directorate B – Circular Economy and Green Growth
Unit B.2 – Sustainable Chemicals
BU 9
B-1049 Brussels

Denis Mottet
Scientific officer
Risk Management Unit II
European Chemicals Agency
PO Box 400 / Annankatu 18
00121 HELSINKI, Finland

Main contributors

Liz Nicol, Julius Kreißig, Caspar Corden, Ian Keyte, Rob Whiting, Alex Matulina, David Tyrer, Marc Söllner, Leonie Constantine (Wood);
Miriam Schöpel, Milos Milunov, Alexandra Polcher (Ramboll);
Marlies Warming, Carsten Lassen (COWI)

Issued by

………………………………………………………………

Julius Kreißig

Approved by

………………………………………………………………

Caspar Corden

Wood

Floor 23
25 Canada Square
Canary Wharf
London E14 5LB
United Kingdom
Tel +44 (0) 203 215 1610

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Document revisions

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1	Interim report	19/07/2019
2	Draft final report (working draft for info)	09/12/2019
3	Draft final report	10/12/2019
4	Final report	17/04/2020
5	Final report (issue 2)	22/05/2020
6	Final report (issue 3)	05/06/2020

Executive summary

Purpose of this report

This is the combined final report for two studies on "*The use of PFASs and fluorine-free alternatives in fire-fighting foams*" (commissioned by the European Commission) and an "*Assessment of alternatives to PFAS-containing fire-fighting foams and the socio-economic impacts of substitution*" (commissioned by ECHA), prepared by Wood working in partnership with Ramboll and COWI.

The overall aim of the report is to collect information to support the assessment of potential regulatory management options to address the human health and environmental risks associated with the use of PFAS in fire-fighting foams in the EU, as well as providing that information in the format of a REACH Annex XV dossier.

Key results

Substance identification

Three substance classes were considered:

- PFAS substances, including various carboxylic/sulfonic short- and long chain PFAS and a variety of fluorotelomers were found to be (or to have been) used in fire-fighting foams. These substances differ in chain length and substitution and only a relatively small amount of these substances could be identified by CAS/EC number. Furthermore, other PFAS substances were found, that do not belong to any of the named PFAS-categories;
- Fluorinated but non-PFAS alternatives. No examples of the use of such substance was identified, and this was confirmed by external experts and stakeholders. These were therefore not considered further; and
- The identified fluorine-free PFAS-replacements can be grouped into four classes: hydrocarbons, detergents, siloxanes and proteins. For the latter two classes, the information gathered and the number of identified substances is relatively small[1]. In the case of the siloxanes, the usage of these substances in firefighting foams is still under development. In contrast to this, a variety of hydrocarbons (around 24) and detergents (33) were identified, that are used as a replacement for PFAS-substances.

In summary, a large number of highly diverse PFAS substances were found in the context of use in fire-fighting foams. This could be an indication of extensive replacement chemistry that was initiated due to industry and regulatory concerns about the potential health and environmental impacts of long-chain PFAS and lately also short-chain PFAS.

Based on these results, a proposal for a definition is provided in the form of a substance identity description that could be used when consulting further on the impacts of a potential restriction.

[1] However a possible issue with the protein-based alternatives is that many of these will not be identified by a standard identifier (e.g. CAS number) and so they may have been underrepresented in the data reviewed on the alternatives.

Market analysis

Based on information provided by Eurofeu and individual fire-fighting foam manufacturers, it has been estimated that at least 14,000 tonnes, but probably as much as around 20,000 tonnes of PFAS-based fire-fighting foams are sold in the EU annually. The main application is the chemical and petrochemical industry, which employs 59% of these foams. This is followed by municipal fire brigades, marine applications, airports and the military. The foams are used in fire incidents, tests and training exercises, and may also be released via spills. There are likely several tens or potentially hundreds of thousands of facilities using (or at least holding) fire-fighting foams, not counting those only having fire-extinguishers. Prices for PFAS-based fire-fighting foams are highly variable and range from €2 to €30 per litre for concentrates, with the average estimated at around €3 per litre (though this is subject to significant uncertainty).

For fluorine-free firefighting foams, it has been estimated that at least some 7,000 tonnes, but probably as much as around 9,000 tonnes of are sold in the EU annually. A breakdown by chemical group of alternatives (based on the grouping established in the substance identification) is not available, but consultation responses suggest that the main alternatives used are based on hydrocarbon surfactants and detergents. The split by sector of use varies considerably from that of PFAS-based foams, with a much larger share used by municipal fire brigades but a much smaller share in the chemical/petrochemical sectors. Prices for fluorine-free foams range from €0.7 to €10 per litre, with the average estimated around €3 per litre (and again this is subject to significant uncertainty).

Emissions and hazards

Using a source-flow model and various assumptions, emission estimates have been developed to provide an illustrative assessment to help better understand the material flow and key emission compartments of fire-fighting foams. The source-flow model has been used to produce emission estimates for 10 unique non-fluorinated substances (hydrocarbons and detergents); as well as two PFAS-based substances. The results indicate that fresh surface water and soil are the key receiving environmental compartments. For non-fluorinated substances, live incidents are the major point of release, while for PFAS live incidents are still significant but the waste phase is the larger life-cycle stage for emissions, primarily from losses associated with releases at WWTPs.

A review of hazards for these substances based on PNECs and data on biodegradation and bioaccumulation was also undertaken. This suggests that the two PFAS substances should be considered as being of greater hazard and greater potential environmental risk compared to the non-fluorinated substances. This is due to the PFAS being both non-biodegradable and having relatively low PNECs for water and soil. Some of the alternative substances exhibit low PNECs, however, this needs to be considered in the context of their ready biodegradation. It should be noted however that data availability on the hazards and properties of the alternatives is not always comparable to that of the PFAS substances.

Remediation costs and technologies

A distinction is made in this report between more costly 'remediation' relating to long-term accumulation of contamination, and the less-costly and more short-term 'clean-up' of geographically-contained contamination from recent activities. For PFAS-containing foams, remediation is warranted and likely required by regulatory agencies when sensitive receptors (including groundwater) are threatened or already impacted. Typically, a risk-based remediation approach would be implemented by describing the risk to relevant receptors based on analytical data collected from environmental media such as soil, surface water and/or groundwater. Clean-up is driven to a large degree by the flammable liquid itself, the soot, water and "dirt" in general terms that contribute to the fire-fighting water runoff and its potential to affect the environment.

The most relevant technologies for the remediation of PFAS resulting from fire-fighting foam use are identified and potential costs estimated, although these are highly site-specific and can vary considerably. Commonly used soil remediation technologies include excavation and landfilling or incineration, and soil capping. For coarser-grained soil, soil washing can be an option which is in use at sites featuring the right geological setting. However, soil washing water will require subsequent treatment, and the finer soil fraction needs to be treated in a different fashion (landfilling, incineration). Water treatment (including groundwater, surface water, and storm-/ waste water) typically include adsorption of PFAS compounds from the aqueous matrix onto an adsorbent such as granular activated carbon (GAC), or resins (non-regenerable or regenerable). The typical costs per site can range from around half a million Euros (only soil remediation required, lower estimate) to just over €100 million (sum of soil excavation and incineration, groundwater pump and treat and drinking water reverse osmosis, higher estimates).

Analysis of Alternatives

Seven fluorine-free fire-fighting foams are selected from a list of more than 30 products marketed as alternatives to PFAS-based fire-fighting foams. These are considered to be representative of the products on the market for the most critical uses of fire-fighting foams for liquid hydrocarbon fires and of products that are in actual use. An overall assessment of the technical feasibility, economic feasibility, and availability of these seven alternatives is undertaken. In addition, two case stories about transitions to fluorine-free alternatives in the aviation and petrochemicals sectors are presented.

It is concluded that alternatives are generally available and technically feasible and have been successfully implemented by many users in most of the main user sectors identified. Use areas where PFAS-free alternatives have not been fully tested, are in the downstream petrochemical sector (refineries and steam crackers) and large storage tank facilities. In particular, combatting fires involving large storage tanks requires foams capable of flowing on large burning liquid surfaces and sealing against hot metal surfaces to prevent reignition. More testing is required to prove performance of alternatives under some conditions. To date, no real-world examples of a successful transition in installations with large tanks have been identified.

Socio-economic analysis

Two main restriction scenarios are considered in the analysis:

- Scenario 1: Restriction (ban) on the placing on the market of PFAS-based FFF. The use of legacy foams, i.e. foams already in stock at producers' or users' sites, would still be permitted. So, under this scenario, new sales would be prevented but existing stocks could be used and run down incrementally; and
- Scenario 2: Restriction (ban) on the placing on the market and the use of PFAS-based FFF. In addition to a restriction on sale, legacy foams, i.e. foams already in stock at producers' or users' sites, would need to be disposed of safely. So, under this scenario, not only would new sales be prevented, but existing stocks would also need to be disposed of and replaced with new volumes of fluorine-free foams.

Both scenarios require purchasing of alternative foams which is estimated to incur additional costs (compared to the baseline) of around €27m per year in the EU. This would be partly off-set by savings, e.g. from lower disposal cost of fluorine-free foams when they reach their expiry date. However, Scenario 2 would also require existing stocks of PFAS-based foams to be written off, and new stocks would have to be purchased, subject to replacement costs (minus the value of existing stocks already depreciated) estimated at around €1.0 billion (range -€60 million[2] to €8.3 billion). In Scenario 2, additional costs would also be incurred for the disposal of the existing stocks of PFAS-based foams. Total EU costs (one-off) are estimated at up to €320 million (range up to €60m to €4.8bn). There are other potential economic costs for transitioning that are difficult to quantify, of which cleaning/replacement of equipment before switching the foam are likely the most important. These costs could be significant (e.g. costs of cleaning could potentially be in the order of €1 billion, depending on the residual concentration limit and number of installations affected).

There are potentially significant benefits in terms of reduced clean-up / remediation costs for PFAS-contaminated sites. As a very high-level estimate for illustration, the potential order of magnitude of avoided remediation could be hundreds of millions of Euros to billions of Euros. Treatment costs for run-off could be around €0.7 per litre (range ca €0-€11) or up to tens of millions of Euro per incident less expensive when fluorine-free foams are used, but data on the total amount of fire-water run-off treated was lacking to quantify an EU total. In cases where fire-water run-off is not contained and further clean-up is required, clean-up costs may also be lower for fluorine-free foams due to their lower persistence. No specific data was available to quantify this saving, but for illustration the potential order of magnitude of savings could be several million Euros.

Regulatory management option analysis (pre-RMOA)

The RMOA discusses the need for further regulatory management of the concerns associated with the use of PFAS in fire-fighting foams. Significant hazards have been shown at least for some PFAS, including some short-chain PFAS. However, the hazards of PFAS themselves were not a primary focus of this study, given ongoing work by the PFAS working group[3]. Many PFAS are highly mobile, highly persistent, have the potential to accumulate within the environment and living organisms, and to cause cross-border pollution. There is a lack of existing regulation, and of implementation or proven effectiveness of other risk management measures to address the release of PFAS from the use of PFAS-based fire-fighting foams. National regulation does not appear to be forthcoming and discrepancies across Member States could affect the functioning of the internal market. It is therefore concluded that a restriction on the placing on the market (and potentially the use) of PFAS-containing fire-fighting foams at EU-level appears to be an appropriate option.

In order to maximise effectiveness while minimising potential adverse socio-economic impacts of such a restriction, it appears appropriate to vary the specific conditions (particularly transition periods) by application and user sectors, because of their significant divergence in terms of the likelihood of emissions and implications of switching to alternative foams. It is concluded that training and testing should be the highest priority for a quick transition to fluorine-free foams. Chemicals / petrochemicals is the largest user sector. Users have suggested a longer transition period of up to 10 years is required and derogations with a longer transition period may be needed for specific applications (notably large tank fires) where further testing is required to determine the technical feasibility of alternatives and potential fire-safety risks from using alternatives may be higher (and are still under investigation). This is the largest user sector, so in order to ensure effectiveness of a restriction in reducing PFAS-emissions, it seems appropriate that any longer transition period should be limited to the most sensitive applications within this sector, particularly large incidents and large atmospheric storage tanks. For small incidents[4] as well as all other sectors, shorter transition periods between 3-6 years have been suggested and are expected to minimise socio-economic implications of a restriction.

[2] I.e. a potential saving of €60 million, if fluorine-free alternatives are less expensive than the PFAS-based foams they replace (possible in some cases but unlikely on average) and no additional volumes are required.
[3] A working group under ECHA's stewardship to assess the hazards associated with PFAS substances, including persistence, mobility, bioaccumulation and toxicity.
[4] Note that the distinction between small and large incidents is based on stakeholder feedback and would need to be more precisely defined, for instance in any consultation as part of a potential future restriction proposal.

Regarding thresholds for the remaining concentration of PFAS in equipment that previously used PFAS-based fire-fighting foams, a balance would need to be struck between the amount of PFAS emissions remaining if a given threshold is adopted, versus the costs of cleaning imposed in order to achieve that threshold. Stakeholder input suggests that 100 ppb can be achieved with a relatively simple cleaning process (cost likely low but not quantified); such a limit would remove the vast majority of emissions. Lower thresholds are achievable with more complex and costly processes. For instance, achieving 1 ppb could cost around €12,300 per appliance according to one estimate, which could imply EU total costs in the order of €1 billion. However, setting a lower concentration threshold would lead to a relatively small additional reduction in PFAS emissions, compared to the overall reduction achieved by the restriction.

Lastly, it is advisable to further investigate a potential obligation to apply best practice emission reduction measures during and after the use of PFAS-based fire-fighting foam, as a condition of any restriction. These could cover, for instance, containment, treatment, and proper disposal of foams and fire water run-off. These measures could provide relatively effective reduction of PFAS-emissions at relatively low cost particularly during the transition periods when PFAS-based foams continue to be used in certain applications and if the use of existing foams is not restricted (scenario 1).

Contents

1. Introduction

1.1 This report

Wood has been contracted by the European Commission, DG Environment ('DG ENV') and by the European Chemicals Agency ('ECHA') to provide services on:

- "*The use of PFASs and fluorine-free alternatives in fire-fighting foams*" (the 'DG ENV study')[5]; and
- "*Assessment of alternatives to PFAS-containing fire-fighting foams and the socio-economic impacts of substitution*" (the 'ECHA study')[6].

Wood is working in partnership with Ramboll on the DG ENV study and with COWI on the ECHA study, both acting as subcontractors to Wood.

This is the combined final report for both studies, which contains details of the results for all tasks under the two studies. For convenience, the full scope of work for both studies is set out below, based on the scope of work confirmed at project inception.

1.2 Scope of work

Objectives

DG ENV study

As set out in the Terms of Reference the overall objective of this project is to assess the use of polyfluoroalkyl and perfluoroalkyl substances (PFAS) and fluorine-free alternatives in fire-fighting foams, looking specifically at:

i. their volumes of use;

ii. their functionality;

iii. their emissions to the environment; and

iv. the costs for remediation of soil and water due to environmental release.

The specific objectives within this are to:

- Assess the potential hazard (and risk, to the extent possible) of fluorine-free alternatives, with regard to human health, the environment and humans exposed via the environment;
- Assess the cost and technologies for remediation of soil and water for both "long chain" and "short chain" PFAS and for the fluorine-free alternatives; and
- Consider the above points for both foams already on the market and installed in fire-fighting systems (both fixed and mobile), as well as foams not yet in use.

[5] Reference 07.0203/2018/791749/ENV.B.2 under the Framework Contract ENV.A.3/FRA/2015/0010.

[6] Reference ECHA/2018/561 under Framework Contract ECHA/2015/50.

ECHA study

The terms of reference for the ECHA study state that the project should assess the technical feasibility, economic feasibility and availability of alternatives to PFAS-containing fire-fighting foams and the socio-economic impacts of substitution, broken down into the following tasks:

Task 1:

- Technical feasibility;
- Economic feasibility; and
- Availability of alternatives to PFAS-containing fire-fighting foams.

Task 2:

- Socio-economic impacts of substitution of PFAS-containing fire-fighting foams.

Task 3:

- Support in organising a workshop to collect the input of the various stakeholders (including producers and users of fire-fighting foams).

Tasks

DG ENV study

Task 1 – Substance identification - input for the scope of a possible measure

Identify the PFAS (long and short chain), their salts and precursors present or potentially present in fire-fighting foams, including those intentionally used and those that might be present as impurities. Identify the constituents of the fluorine-free fire-fighting foams and any non-PFAS fluorinated alternatives, if they exist. This task should be performed in close cooperation with the ECHA study, especially when consulting stakeholders.

Task 2 – Market analysis

Estimate the tonnages of fluorine-based and fluorine-free fire-fighting foams manufactured and placed on the market in the EU. The analysis is to include the different functions (e.g. film-forming, surfactants, solvents) provided by different components of fire-fighting foams and the type of fires for which their use is recommended. The comparison between the function provided by PFAS-based and fluorine-free foams will be part of the ECHA Analysis of Alternatives. A large consultation with manufacturers and professional users of fire-fighting foams is to be organised.

Task 3 – Assessment of the emissions and hazard of fluorine-free foams

Estimate the emissions of PFAS and of the constituents of the alternative fluorine-free fire-fighting foams to the environment, broken down by environmental compartment (aquatic environment (marine and inland waters), terrestrial environment) and the possible uptake by humans via the consumption of food and water. While the hazard of PFAS will be part of the work of the PFAS Working Group, the study should also assess the hazard (and risk, to the extent possible) to human health, to the environment and to humans via the environment of the fluorine-free foams and any non-PFAS fluorinated alternatives, if they exist.

Such assessment shall follow the relevant guidance provided by ECHA[7].

[7] See available guidance documents at: https://echa.europa.eu/guidance-documents/guidance-on-reach

Task 4 – Assessment of the remediation costs

Assess the cost and technologies for remediation of soil and drinking water for both "long chain" and "short chain" PFAS and for the alternatives. It should consider both foams not yet in use and those already installed in the fire-fighting systems (both fixed and mobile).

Task 5 – Summary of the information in the form of a risk management option analysis (pre-RMOA)

Summarise all the information following the structure of a RMOA ("pre-RMOA) to allow the Commission to identify the most appropriate instrument for possible regulatory risk management activities to address the concerns resulting from the use of PFAS in fire-fighting foams. The draft pre-RMOA is to be included in the interim report. The final pre-RMOA is to include the findings of the ECHA study on the Analysis of Alternatives and Socio-Economic impacts and the outcome of the work of the PFAS Working Group on the hazard of PFAS.

Task 6 – "Pre-Annex XV dossier"

Present the full information collected (including the part developed by the ECHA study and the hazard of PFAS developed by the PFAS Working Group) in the form of an Annex XV dossier, so that the Commission can use it as a basis for any future regulatory action, if this is considered necessary.

The DG ENV study also includes contributing to the organisation of the workshop (preparing the agenda, contacting the experts, preparing the supporting documentation and reporting). More details on the workshop are provided in Task 3 of the ECHA study.

ECHA study

Task 1 – Analysis of alternatives to PFAS-containing fire-fighting foams

Analyse the alternatives in terms of:

1. **Technical feasibility**. Including, but not necessarily limited to aspects such as:
    - Comparison between the function provided by PFAS-containing foams and their alternatives;
    - Performance (efficacy) to fight various types of fires, including liquid fuel fires ("Class B" fires);
    - Required machinery/equipment/storage tanks; and
    - Uses where alternatives do not meet (fully or partially) the required performance and why.
2. **Economic feasibility.** Including, but not necessarily limited to aspects such as:
    - Annualised cost for an assessment period that takes into account the investment cycle in the industry;
    - Cost difference of bringing forward investment(s);
    - Required amounts/loadings of alternative foams;
    - Price per kg;
    - Shelf life;
    - Machinery/equipment/storage tanks changes;
    - Any need for specific training to use the alternative foams;
    - Possible savings to fire-fighting users;

- Training (e.g. benefits of being able to practice with the alternative foams with minimal cleaning requirement);
- Possible instant clean up after fire made unnecessary or less expensive;
- For PFAS-containing foams already placed on the market;
- Incineration costs (including transfer and availability of technically suitable incinerators); and
- Clean-up of tanks (considering practical concentration limit, i.e. remaining PFAS concentrations achievable with reasonable cost).

3. **Availability of alternatives**
    - Whether and when alternatives are available in the required quantities. If not, expected time to reach the necessary quantities.

Task 2 – Assessment of the socio-economic impacts of substituting PFAS-containing fire-fighting foams

Assess, considering the scenario(s) of an EU-wide restriction or total ban of the use of PFAS-containing foam, and the socio-economic impacts of such restriction/ban scenarios:

Including, but not necessarily limited to aspects such as:

- The likely reaction of producers and users of fire-fighting foams (both PFAS-containing and alternatives) in and outside the EU;
- The likely related impacts to this restriction (e.g. as reduced emissions of fluorinated substances or other hazardous chemicals, fire safety aspects, and economic impacts to the foam producers and their users); and
- The likely impact of different transitional periods.

Task 3 – Supporting the organisation of a stakeholders' workshop

Support ECHA and the Commission in the organisation of a workshop in the EU gathering the most relevant stakeholders to collect their input. In collaboration with ECHA and the Commission:

- Define the best suitable time for organising the workshop, in light of the timing of ECHA's and Commission's studies requirements;
- Draft the workshop agenda and description;
- Identify the key elements for discussion/information requirements to be addressed in the workshop;
- Identify and contact the relevant stakeholders to invite, including the speakers;
- Prepare short background materials to be sent to the participants in advance of the workshop;
- Prepare presentations on the context of ECHA's study and the required input from stakeholders;
- Assist ECHA and, the Commission in running the discussions during the workshop to achieve the desired outcome;
- Provide assistance in drawing the conclusions from the workshop; and
- Short report on stakeholder workshop (including a high-level summary and first conclusions).

Task 4 of the ECHA study was optional and will no longer be necessary as the overlap in project team members allows for the ready exchange of information between both projects.

1.3 Structure of this report

This report is structured as follows:

- Part 1, consisting of Section 2 only, provides an overview of the consultation undertaken jointly between the ECHA study and the DG ENV study;
- Part 2 presents the following tasks of the DG ENV study:
  - The approach and detailed results of the substance identification (Task 1) are presented in Section 3;
  - An overview of approach and results of the market analysis (Task 2) are presented in Section 4;
  - The assessment of the emissions and hazard of PFAS substances and their alternatives (Task 3) is presented in Section 5; and
  - Section 6 provides an assessment of the remediation costs associated with PFAS-based fire-fighting foams and potential alternatives (Task 4).
- Part 3 then focuses on the tasks of the ECHA study:
  - The approach and results of the Analysis of Alternatives (Task 1) is presented in Section 7; and
  - Section 8 presents the outcomes of the SEA (Task 2).
- Part 4, consisting of Section 9 only, summarises all the above results in the format of a pre-RMOA (DG ENV study Task 5); and
- The information collected is also presented in the form of an Annex XV dossier (DG ENV study Task 6), in Appendix 7.

PART 1 – Joint consultation

2. Joint consultation

2.1 Introduction

In the inception of both Commission and ECHA projects, it was recognised that effective engagement with key stakeholders from across the fire-fighting foam sector, particularly the manufacturers and users of the foams, would be critically important in the data collection process of both projects. It was also noted that the relevant stakeholders, who would be likely to be able to contribute key information, would be able to feed into both projects. Therefore, to conduct both projects with optimal efficiency, and to ensure the consistency of the data feeding into both projects, it was agreed to carry out a joint stakeholder consultation across the two projects in parallel.

It was agreed that it was essential that the consultation cover all the relevant sectors and backgrounds across the fire-fighting foam supply chain, as well as regulators, researchers and special interest groups. The consultation therefore aimed to target the following stakeholders:

- Foam manufacturers / suppliers;
- Users of foams in major sectors (including airports, oil and gas, chemical plants, ports, railways);
- Key trade associations;
- International organisations;
- National-level authorities and agencies;
- Academics and R+D (especially those involved in developing alternative foam products); and
- Key NGOs and interest groups.

It was agreed during the inception meeting that Wood, Ramboll and COWI would map stakeholders identified so far, indicating the best means of consulting each one of them: e.g. advisory group, questionnaire, one-to-one consultation, workshop, etc. An initial list of stakeholders was provided in the Inception report, and a finalised list was agreed with the Commission and ECHA prior to commencing the consultation activities.

2.2 Approach

The agreed approach to collecting key information from the main categories of expert stakeholders (detailed above) was to carry out a consultation through a combination of i) scoping interviews, ii) a targeted stakeholder questionnaire, and iii) a stakeholder workshop. Our approach to carrying out these consultation activities is outlined in the following sections.

Scoping interviews

To inform the main data collection steps of the project (the stakeholder questionnaire and workshop) a series of initial scoping interviews was organised with a selected small number of key stakeholders. The purpose of the interviews was to:

I. Introduce and discuss the aims and scope of the project with key experts;
II. Identify where the key data gaps were in relation to the objectives of the project(s); and
III. Identify other key stakeholders in this sector to target in the next stages of the consultation.

The stakeholders involved with the scoping interviews were:

- Eurofeu;
- Fire Fighting Foams Coalition;
- Copenhagen Airport;
- Heathrow Airport;
- LASTFIRE project; and
- IPEN.

An interview template was developed, and shared with the interviewees ahead of the call, to guide the conversation more effectively and efficiently. Teleconference interviews of 30-60 minutes were held with each stakeholder. During the call, brief notes of the key discussion points were made.

Since the purpose of these scoping interviews, was as an introductory discussion, rather than an evidence gathering exercise as such, a limited amount of specific information about the use of fire-fighting foam products was gained. A number of key outcomes from these scoping interviews are highlighted below:

- All stakeholders interviewed expressed an interest in the project and agreed to participate in the consultation;
- In some cases, for example, for key industry associations, it was agreed they would coordinate joint industry responses, and stakeholders provided the details of additional stakeholders to contact, and/or agreed to forward the consultation on directly;
- Both industry, users and others (e.g. NGOs) commented on the increased move towards and the rapidly increasing market share of fluorine-free foams, and their increasingly better overall performance now than previously;
- It was re-emphasised that alternative foams are designed for very specific applications, requiring compliance with specific performance criteria, so the analysis of their technical and economic feasibility will be challenging as it requires assessment of each product individually;
- There is likely to be variation in the situations with regards to alternative foams in different sectors of use (e.g. between aviation and oil and gas sectors) and in different locations/countries (e.g. certain countries have switched to alternatives, others have not); and
- The potential for contamination of foams was raised, leading to the inclusion of specific questions in the survey about the level of PFAS as impurities in foam products (both PFAS-based and fluorine-free).

The scoping interviews were then used to better inform our approach to the following consultation steps, allowing the survey and workshop to be designed more systematically to address the key knowledge gaps and target the most relevant stakeholders. This also helped to identify additional stakeholders to include in the next consultation steps.

Consultation questionnaire

The main consultation activity conducted involved the development of a written questionnaire, based on an assessment of the required data needed to generate and/or complement the information already gathered under the separate Tasks under the two projects.

It was agreed that the most appropriate format of the questionnaire would be a Word document that could be sent to targeted stakeholders directly via email, allowing the respondents to fill in relevant details and return the completed questionnaires.

The questionnaire covered the following aspects:

- Introductory information;
- Background information on the respondent;
- Chemical identity, functionality of PFAS in fire-fighting foams;
- Alternatives to PFAS in fire-fighting foams;
- Foam use and environmental emissions;
- Potential restrictions on PFAS in fire-fighting foams; and
- Additional information.

The full consultation questionnaire is provided in Appendix 1 of this report.

2.3 Consultation questionnaire results

A total of 33 written responses to the questionnaire were received[8].

Of the different types of stakeholder targeted, the most responses were from users/industry (11), with smaller numbers of responses from individual manufacturers (2), authorities/agencies (6), industry associations (2), NGOs (3) and 'other' stakeholders (7) e.g. academic/testing/training professionals/technical consultant. It is noted that the responses from the users of foams cover all the main sectors of use the consultation aimed to cover (airports, oil refineries/storage, chemicals, petrochemicals, and rail).

Responses to the consultation from a number of stakeholders also included the provision of previously published data or reports in addition to, or instead of, the questionnaire. This included published reports and analyses from national authorities[9], research and testing information[10], and special interest groups[11]

Since the questions in the stakeholder questionnaire were designed to gather information that will best feed into the delivery of tasks under each of the two projects, the responses received have generated useful information in this context. In particular, we highlight the following aspects, where the consultation yielded useful information:

- Identifying some of the key foam products containing PFAS on the EU market, and non-PFAS alternatives actually used in key sectors;
- Identifying specific PFAS, precursors and impurities present in some foam products;

[8] Correct as of July 18 2019.
[9] KEMI (2015) Chemical Analysis of Selected Fire-fighting Foams on the Swedish Market 2014
[10] Published testing data, as provided by LASTFIRE: www.lastfire.co.uk/
[11] IPEN (2019) The Global PFAS Problem: Fluorine-Free Alternatives as Solutions, https://ipen.org/documents/global-pfas-problem-fluorine-free-alternatives-solutions

- The functionality of PFAS-containing foams useful to the major users of foams and reasons why products containing PFAS have not been fully replaced;
- Volumes of production and use, and unit price for a small number of individual products;
- Information on available alternatives, including specific products on the market in the EU, the type and sector of use, their availability, volumes of sale and use, their perceived technical feasibility and economic feasibility (see Section 3, Task 1 analysis of alternatives);
- Some details of fire-fighting foam use e.g. volumes, frequency;
- Some details of methods, regulations, and guidelines in place to prevent release to the environment;
- Some information on the methods/approach to disposal of individual foam products;
- Preliminary stakeholder opinions and feedback on different potential restriction options were provided; and
- Additional data, reports and other resources were provided by a number of stakeholders with their consultation response.

For some sections, a number of information gaps, where the level of detail provided by respondents was less substantial, were identified. These data gaps helped to inform the approach to the organisation and format of the following stage of the consultation process, the stakeholder workshop, where these data gaps were explored further (see Section 2.4).

2.4 Consultation workshop

The final stage of the consultation involved the organisation of an expert stakeholder workshop. This was hosted by ECHA in Helsinki on 24 September 2019.

The purpose of the workshop was to present, validate and seek feedback on the preliminary project findings; gather views on possible risk management options; and explore the feasibility of replacing PFAS-based foams with fluorine-free alternatives. Stakeholder views were sought during the workshop through a series of breakout groups on key topics which focused on specific questions designed to inform possible future regulatory activities.

The workshop was attended by a total of 36 participants, including manufacturers, users from different sectors (airports, chemical plants, oil and gas), researchers, NGOs, national authorities, and remediation experts.

The format of the workshop included:

- Introductions from DG Environment, ECHA and the study team;
- Presentation of initial results;
- Plenary discussion on study findings to date;
- Presentations from invited speakers; and
- Breakout session on remaining data gaps.

The invited speakers, who presented at the workshop were from the following organisations:

- Eurofeu (industry perspective);

- Finavia Corporation (user perspective – airports);
- Total HSE (user perspective – oil and gas); and
- LASTFIRE project (testing and efficacy perspective).

There were four breakout sessions for the workshop, each covering a specific set of questions, partly informed by the identified data gaps remaining from the consultation questionnaire and the other tasks relating to the two projects. The breakout sessions covered the following aspects:

- Different Risk Management Options;
- Essential uses and availability of alternatives;
- Remediation costs and technologies; and
- Current/ future market trends in PFAS-based and fluorine-free foams.

The workshop report with more details about the set-up and results of the workshop is included in Appendix 2.

2.5 Additional consultation and resources

The stakeholder consultation and workshop also resulted in a number of stakeholders providing additional information to supplement their consultation responses. This additional information was used, where relevant, in each of the specific tasks.

Following the consultation questionnaire and workshop, a number of specific areas were identified as needing additional data or clarification, for example on volumes of firefighting foams produced, marketed and used in the EU. Where these additional data needs were identified, the project team undertook direct consultation with specific stakeholders identified as being the best source of the required information. Contact was made with these stakeholders via email or telephone to discuss the remaining data needs and obtain the required data. This additional consultation has provided additional detail and clarifications relating to critical uses, volume of production and use in the EU, and experiences from previous transitions.

PART 2 – DG ENV STUDY

3. Task 1. Substance identification

3.1 Introduction

The objective of this task is to identify the PFAS (including long and short chain, their salts and precursors, intentionally used or as impurities) present in fire-fighting foams, the constituents of the fluorine-free fire-fighting foams and any non-PFAS fluorinated alternatives (if they exist).

In the following, the approach is briefly described (Section 3.2). Then, interim results are discussed in Section 3.3, in separate sub-sections first for alternatives to PFAS in fire-fighting foam that are fluorinated (but not based on PFAS), then for completely fluorine-free alternatives, and lastly for PFAS used in fire-fighting foams.

3.2 Approach

The substance identification was based on desktop research covering:

- Literature research based on:
  - Scientific peer reviewed literature (pubmed, google scholar);
  - Reports or other publications by national and regional environmental agencies; and
  - Reports or other publications by NGOs.
- Information gathered in the framework of regulations:
  - REACH (for example RMOAs, Annex XV restriction reports, RAC & SEAC documents of PFAS substances);
  - Stockholm convention (for example risk management evaluation, AoA reports, technical paper on the identification and assessment of alternatives); and
  - Basel Convention (technical guidelines).
- Safety Data Sheets ((M)SDS) and any other information of known producers/associations;
- Environmental and human (bio-)monitoring data and case studies; and
- Expert knowledge (international experts).

In general, all the above-named documents were screened by using the following search terms: fire, foam, fluor and/or alternative. More specifically, in case the documents covered the analysis of alternatives (e.g. documents by REACH, Stockholm and NGOs) the documents were screened using the search terms fire and foam. This strategy was also undertaken in the screening of more general reports, for example those reports that cover PFAS in general. These kinds of reports were mostly published by environmental agencies.

In cases where analytical measurements were reported (case studies, (bio-) monitoring and scientific publications) it was made sure, that an unambiguous assignment to the usage of fire-fighting foam could be made. Only in cases where this was possible, the respective data was extracted.

A different strategy was elaborated for (M)SDS, in this case only the term "fluor" was used.

More detail about the specific search terms applied and the specific documents screened is provided alongside the results in the following sub-sections.

A matrix was created to collect all potentially relevant information from the literature review, but the identified information is summarised in the following.

3.3 Final results

Task 1.1: Substance identification non-PFAS fluorinated alternatives

Due to concerns about their toxicity and regulatory pressure, long chain PFAS (such as C8, see definition later in this section) have been widely replaced by (perceived safer) alternative substances starting from the early 2000s. These alternatives include short-chain substances like C6 fluorotelomer based fluorosurfactants[12], but also non-fluorinated substances.

The knowledge of the chemical identity of these substances is currently very limited. As reflected in the Terms of Reference of this project, it is clear that a variety of PFAS and fluorine free-substances are used in fire-fighting foams, but it is not certain if there are any non-PFAS but fluorinated substances that have been or are still being used in fire-fighting foams.

The distinction between PFAS and non-PFAS fluorinated substances is the following: PFAS are a fully (per) or partly (poly) fluorinated carbon chain that "contain one or more C atoms on which all the hydrogen atoms are substituted (present in the non-fluorinated analogues from which they are notionally derived) by F atoms, in such a manner that they contain the perfluoroalkyl moiety (CnF2n+1–)." (OECD 2018). Non-PFAS fluorinated substances do not exhibit this particular feature of having "one or more C atoms on which all the H- are substituted by F-atoms". An example for this substance group are silicon dioxide molecules which are perfluorinated. These substances might be used in textiles as an alternative to PFAS[13]. Based on the length of the fluorinated carbon chain, short and long chain PFASs can be distinguished. Long chains refer to:

- Perfluorocarboxylic acids (PFCAs) with carbon chain lengths C8 and higher, including perfluorooctanoic acid (PFOA);
- Perfluoroalkane sulfonic acids (PFSAs) with carbon chain lengths C6 and higher, including perfluorohexane sulfonic acid (PFHxS) and perfluorooctane sulfonate (PFOS); and
- Precursors of these substances that may be produced or present in products.

Accordingly, short chain PFAS include:

- PFSAs with carbon chain lengths of C5 and lower, including perfluorobutane sulfonic acid (PFBS);
- PFCAs with carbon chain lengths of C7 and lower, including perfluorohexanoic acid (PFHxA); and
- Precursors of these substances may be produced or present in products. Examples are short-chain perfluoroalkyl sulfonyl fluoride-based raw materials and short-chain fluorotelomer-based raw materials.

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[12] Fluorosurfactants are synthetic organofluorine compounds with multiple fluorine atoms. They can be fluorocarbon-based or polyfluorinated (Lehmler, 2005).
[13] https://greensciencepolicy.org/wp-content/uploads/2015/04/Presentation-Stefan-Posner-PFAS-April-2015.pdf

To identify any potential non-PFAS fluorinated substances used in fire-fighting foams, a literature research in pubmed and google scholar was undertaken, using the following search terms:

(("substance" OR "chemical" OR "compound")) AND ("fire fighting foam" OR fire-fighting "fire fighting")

As of April 2019, the pubmed search returned 53 hits. However, the relevant hits covered only poly- and perfluorinated compounds. The same result has been found using google scholar.

SDS/supplier information, monitoring data, EPAs, NGOs, case studies and legislation were also screened for information on non-PFAS fluorinated substances (simultaneously with the screenings for information on the substance identity of PFAS- and fluorine free-chemicals, discussed below). No non-PFAS fluorinated substances could be identified.

In conclusion, the analysis suggests that fluorinated non-PFAS alternatives in the area of fire-fighting foams do not exist. This was confirmed in personal communication by Zhanyun Wang (ETH Zürich), an international expert on PFAS chemicals. It was also discussed and not disputed at the project workshop.

Task 1.2: Substance identification - FFF (fluorine-free foams)

Because of regulatory pressure and consumer preferences for fluorine-free replacements, a lot of producers of PFAS-containing foams have introduced fluorine-free alternatives. Most of the foams are advertised as intended for use on class B hydrocarbon fuel fires such as oil, diesel and aviation fuels as well as class A fires such as wood, paper, textiles etc.

As explained above, various information sources have been reviewed in order to identify any relevant alternative to PFAS in fire-fighting foams. Many of these sources did not provide chemical names or/and CAS/EC numbers. In a lot of sources (e.g. from NGOs, ECHA and Stockholm Convention documents), only very general hints on replacement substances or substance groups have been identified. This includes the naming of the following substance groups:

1. Hydrocarbons;
2. Detergents;
3. Siloxanes; and
4. Protein foams.

However, more specific information on substances in FFF was identified in SDS and/or supplier information, some reports published by national authorities, and some peer-reviewed publications. Most relevant information was identified in SDS. As an additional source patents were considered using the google patent search. The results were in most cases the same as for the SDS.

A report by the Swedish chemicals agency (KEMI) compiles available knowledge about fire-fighting foams that were available on the Swedish market in 2014, with respect to chemical content, use, handling and disposal[14]. Scientific peer-reviewed publications by Hetzer et al. highlighted various sugar-based siloxanes (Hetzer, R. et al. ; Hetzer, R. et al. 2014; Hetzer, R. H. und Kümmerlen 2016; Hetzer, R. H. et al. 2015). However, to our knowledge no CAS-numbers are available for these chemical compounds.

In the following, the identified substances are presented in more detail. In general, AFFF concentrates are themselves mostly water, with other components such as surfactants, solvents and stabilisers. The lowering of surface tension to allow formation of foam and hence a blanket over the source of fuel, may be accomplished by use of both fluorocarbon and hydrocarbon surfactants. In this context, some of the substances identified in this task are not believed to be direct PFAS- replacements in terms of being a surface

[14] https://www.kemi.se/global/pm/2015/pm-6-15.pdf

active agent[15]. In the following, only those substances which were identified by their chemical structure as replacements (R) for PFAS are discussed. It is also possible that some of the identified substances may need to be combined with other substances (for example a hydrocarbon in combination with a detergent) in order to fulfil their capacity as a PFAS-replacement.

However, it should be noted that their suitability as alternatives to PFAS-based fire-fighting foams is discussed in more detail in the analysis of alternatives (Section 7).

For a better overview, the substances were grouped in the following substance groups: hydrocarbons, siloxanes, protein foams and detergents based on expert judgement.

Hydrocarbons

In terms of hydrocarbons, a variety of different substances/substance groups were found. This includes for example various fatty acids, xanthan gums, sugars, alcohols, PEGs and alkanes. These substances are found in a variety of different products from different manufacturers. In the following table more information on this is given. This includes the CAS/EC identifier, the substance name, the chemical group, the supplier and respective product name. The chemical group was assigned based on the authors' knowledge and presented and not disputed at the stakeholder workshop".

Table 3.1 Identified hydrocarbons (identified by CAS) incl. CAS/EC identifier, the substance name, chemical group and the supplier and/or product name

CAS	EC	Substance name	Chemical group	Supplier and Product Name
500-344-6	157627-94-6	Alcohols, C10-16, ethoxylated, sulfates, triethanolammonium salts	Alcohols	N/A (identified via ECHA's dissemination website)
939-523-2		Alcohols, C8-10, ethoxylated, sulfates, sodium salts	Alcohols	N/A (identified via ECHA's dissemination website)
112-53-8	203-982-0	1-Dodecanol	Alcohols	Respondol ATF 3-6%: Angus Fire (Angus International: Angus Fire, National Foam and Eau et Feu.) LS xMax: Dafo Fomtec AB STHAMEX® 2% F6 Multi-purpose detergent foam: Dr Sthamer STHAMEX-SV/HT 1% F-5 #9142: Dr Sthamer
112-72-1	204-000-3	Tetradecanol	Alcohols	Respondol ATF 3-6%: Angus Fire (Angus International: Angus Fire, National Foam and Eau et Feu.) LS xMax: Dafo Fomtec AB STHAMEX® 2% F6 Multi-purpose detergent foam: Dr Sthamer STHAMEX-SV/HT 1% F-5 #9142: Dr Sthamer
160901-27-9	500-464-9	Alcohols, C9-11, ethoxylated, sulphates, ammonium salts	Alcohols	OneSeven of Germany GmbH. OneSeven Foam Concentrate Class A
67762-19-0	500-172-1	Alcohols, C10-16, ethoxylated, sulfates, ammonium salts	Alcohols	Kempartner AB: Meteor Allround Ma-13
67762-41-8	272-490-6	tetradecan-1-ol	Alcohols	Angus Fire: Expandol (aka Expandol 1-3), Expandol LT (aka Expanol 1-3LT)

[15] Those substances are for example antimicrobial agents that are needed for the biological stability of the foam.

CAS	EC	Substance name	Chemical group	Supplier and Product Name
68131-39-5	500-195-7	Alcohols, C12-15, ethoxylated	Alcohols	Verde Environmental Inc (Micro Blaze): Micro-Blaze Out
266-929-0	67701-05-7	Fatty acids, C8-18 and C18-unsatd.	Fatty Acid/oil	N/A (identified via ECHA's dissemination website)
11138-66-2	234-394-2	Xanthan gum	Gum	Auxquimia: Phos-Chek 3×6 Fluorine Free (aka UNIPOL-FF 3/6); Phos-Chek Training Foam 140 Dr Sthamer: Moussol-FF® 3/6 FireRein: Eco-Gel Kempartner AB: Unifoam Bio Yellow Verde Environmental Inc (Micro Blaze) : Micro-Blaze Out
9000-30-0	232-536-8	Cyamopsis gum; Cyanopsis tetragonoloba	Gum	FireRein: Eco-Gel
9005-25-8	232-679-6	Starch	Hydrocarbon	Solberg: US20080196908
120962-03-0	601-748-6	Canola Oil	Oil	Eco-Gel; FireRein
25322-68-3	500-038-2	Poly(oxy-1,2-ethanediyl),α-hydro-ω-hydroxy- Ethane-1,2-diol, ethoxylated	Polyethylene glycol	Dafo Fomtec AB: Fomtec AFFF 1% F, Fomtec AFFF 3% S, Fomtec AFFF 3%
27252-80-8	608-068-9	ALLYLOXY(POLYETHYLENE OXIDE), METHYL ETHER (9-12 EO)	Polyethylene glycol	1% AFFF Denko 3% AFFF Denko 6% AFFF Denko Alcohol AFFF 3% - 6% Single or Double Strength Denko
32612-48-9	608-760-0	Poly(oxy-1,2-ethanediyl), α-sulfo-ω-(dodecyloxy)-, ammonium salt (1:1)	P Polyethylene glycol	Orchidee Fire: Orchidex BlueFoam 3x3
73665-22-2	616-006-7	Poly(oxy- 1,2-ethanediyl), .alpha.-sulfo-.omega.-hydroxy-C6-10-alkyl ethers, sodium salts	Polyethylene glycol	Dr Sthamer: STHAMEX® 2% F6 Multi-purpose detergent foam, STHAMEX® 3% F6 Multi-purpose detergent foam, STHAMEX® K 1% F-15 #9143,STHAMEX-SV/HT 1% F-5 #9142, TRAINING FOAM-N 1% F-0 #9141
96130-61-9	619-194-9	Poly(oxy-1,2-ethanediyl), α-sulfo-ω-hydroxy-, C9-11-alkyl ethers, sodium salts	Polyethylene glycol	Dafo Brand AB: ARC Miljö Dafo Fomtec AB: Fomtec AFFF 1% A, Fomtec AFFF 1% F, Fomtec AFFF 1% Plus, Fomtec AFFF 1% Ultra LT, Fomtec AFFF 3%, Fomtec AFFF 3%ICAO, Fomtec AFFF 3% S, , Fomtec A-skum
308-766-0	98283-67-1	undecyl glucoside	Sugar	N/A (identified via ECHA's dissemination website)
439-070-6	439-070-6	(2R,3R,4S,5S)-2,3,4,5-tetrahydroxyhexanal (2R,3S,4R,5R)-2,3,4,5,6-pentahydroxyhexanal (2S,3S,4S,5R)-2,3,4,5-tetrahydroxy-6-oxohexanoic acid acetic acid calcium	Sugar	N/A (identified via ECHA's dissemination website)

CAS	EC	Substance name	Chemical group	Supplier and Product Name
		dihydride hydrate magnesium dihydride potassium hydride sodium hydride		
110615-47-9	600-975-8	Alkylpolyglycoside C10-16	Sugar	Orchidee Fire: Orchidex BlueFoam 3x3
54549-25-6	259-218-1	(3R,4S,5S,6R)-2-(decyloxy)-6-(hydroxymethyl)oxane-3,4,5-triol	Sugar	Unifoam Bio Yellow
68515-73-1	500-220-1	Alkyl polyglucoside	Sugar	Dafo Brand AB: ARC Miljö Dafo Fomtec AB: Enviro 3x3 Plus, Enviro 3x3 Ultra, Enviro 3x6 Plus, Environ 6x6 Plus, LS aMax, MB -20, Trainer E-lite, Fomtec AFFF 1% A, Fomtec AFFF 1% F, Fomtec AFFF 1% Plus, Fomtec AFFF 1% Ultra LT, Fomtec AFFF 3% ICAO, Fomtec AFFF 3% S, Fomtec AFFF 3% OneSeven of Germany GmbH: OneSeven ® Foam Concentrate Class B-AFFF vs FOCUM: Silvara APC 3x6
N/a	917-341-4	AAlkyl polyglucoside	Sugar	Solberg: US20080196908

Detergents

Chemically, **detergents** belong to the group of hydrocarbons, however in the context of this project this substance group is considered separately. This group is characterised by their amphiphilic nature, being partly hydrophilic (polar) and partly hydrophobic (non-polar). The polar headgroup is needed to ensure their action on surfaces/interfaces (formation of micelles, lowering of the surface tension of water). The substances identified in this group, cover various alkanes that differ in the carbonic chain length (e.g. decyl, lauryl) and the head group (e.g. betaine, sulphates, amido betaines, triethanolamines). A betaine is a quaternary ammonium compound having three methyl groups.

This pattern is to some extent similar to those of the poly- and perfluorinated substances, in which an F-atom replaces the H-atom. In Figure 3.1 sodium octyl sulphate is shown, this substance has been identified in at least ten individual products from several suppliers as an alternative to PFAS substances. The polar head group is highlighted in red and the non-polar alkaline chain is highlighted in blue.

It should be noted, that also PFAS-containing AFFF may also contain some of these detergents (for example STHAMEX® -AFFF 3%).

Figure 3.1 Chemical structure of sodium octyl sulphate

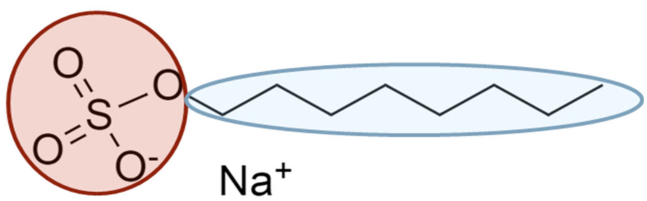


Table 3.2 Identified detergents (identified by CAS) incl. CAS/EC identifier, the substance name, chemical group and the supplier and/or product name

CAS	EC	Substance name	Chemical group	Supplier and Product Name
308062-28-4	608-528-9 / 931-292-6	Amines, C12-14 (even numbered) - alkyldimethyl, N-oxides	Alkylamine	Dafo Fomtec AB: Enviro 3% ICAO, Enviro USP Dr Sthamer: vaPUREx LV 1% F-10 #7141
68155-09-9	268-938-5	Amides, coco, N-(3-(dimethylamino)propyl), N-oxides	Alkylamine	Angus Fire: Syndura (6% fluorine free foam)
70592-80-2	274-687-2	Amines, C10-16-alkyldimethyl, N-oxides	Alkylamine	Angus Fire: Syndura (6% fluorine free foam)
269-087-2	68187-32-6	l-Glutamic acid, N-coco acyl derivs., monosodium salts	Alkylamine	
1469983-49-0	939-455-3	1-Propanaminium, N-(3-aminopropyl)-2-hydroxy-N,N-dimethyl-3-sulfo-, N-(C8-18(even numbered) acyl) derivs., hydroxides, inner salts	Alkylbetaine	Dafo Fomtec AB: Enviro 3x3 Plus, Enviro 3x3 Ultra, Enviro 3x6 Plus, Environ 6x6 Plus, LS aMax, Silvara APC 1
147170-44-3	604-575-4 / 931-333-8	1-Propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-, N-(C8-18(even numbered) and C18 unsaturated acyl) derivs., hydroxides, inner salts	Alkylbetaine	Dr Sthamer: MOUSSOL®–FF 3/6 F-15 #7941
61789-40-0	931-296-8	1-Propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-, N-(C12-18(even numbered) acyl) derivs., hydroxides, inner salts	Alkylbetaine	OneSeven of Germany GmbH: OneSeven Foam Concentrate Class A Solberg: Solberg Patent US20080196908
64265-45-8	264-761-2	N-(2-hydroxyethyl)-N-[2-[(1-oxooctyl)amino]ethyl]-β-alanine	Alkylbetaine	vs FOCUM: Silvara APC 1, Silvara APC 3x3, Silvara APC 3x6, Silvara ZFK (0.5%)
68139-30-0	268-761-3	Cocamidopropyl hydroxysultaine	Alkylbetaine	Solberg: US20080196908
13150-00-0	236-091-0	Sodium 2-[2-[2-(dodecyloxy)ethoxy]ethoxy]ethyl sulphate	Alkylsulfate	Kempartner AB : Unifoam Bio Yellow

CAS	EC	Substance name	Chemical group	Supplier and Product Name
139-96-8	205-388-7	2-[bis(2-hydroxyethyl)amino]ethanol; dodecyl hydrogen sulfate	Alkylsulfate	Dr Sthamer: Sthamex SVM Dr Sthamer: Moussol-FF® 3/6 Kempartner AB: Unifoam S Kempartner AB: Unifoam OneSeven of Germany GmbH: OneSeven ® Foam Concentrate Class B-AFFF vs FOCUM: Silvara 1 (1%) vs FOCUM: Silvara APC 1 vs FOCUM: Silvara APC 3x3 vs FOCUM: Silvara ZFK (0.5%)
142-31-4	205-535-5	Sodium octyl sulphate	Alkylsulfate	Angus Fire (Angus International: Angus Fire, National Foam and Eau et Feu.) : Syndura (6% fluorine free foam) Chemguard: 3% AFFF Foam Concentrate (C303) Chemguard: 3% Low Temp AFFF (C3LT) Dafo Brand AB: AFFF 3-6 % Fire Services Plus: FireAde Fire Services Plus: FireAde AR AFFF OneSeven of Germany GmbH: OneSeven ® Foam Concentrate Class B-AFFF OneSeven of Germany GmbH: OneSeven ® Foam Concentrate Class B-AFFF-AR Solberg : Solberg Patent US20080196908 Dr Sthamer: TRAINING FOAM-N 1% F-0 #9141 vs FOCUM: Silvara ZFK (0.5%)

CAS	EC	Substance name	Chemical group	Supplier and Product Name
142-87-0	205-568-5	Sodium decyl sulfate	Alkylsulfate	Chemguard: 3% AFFF Foam Concentrate (C303) Chemguard: 3% Low Temp AFFF (C3LT) Chemguard: 6% AFFF Foam Concentrate (C603) Chemguard: 6% Low Temp AFFF (C6LT) Dafo Brand AB: AFFF 3-6 % Dafo Fomtec AB: LS xMax Dafo Fomtec AB: MB - 20 Solberg : Solberg Patent US20080196908 Dr Sthamer: TRAINING FOAM-N 1% F-0 #9141 vs FOCUM: Silvara 1 (1%) Solberg : Solberg Patent US20080196908
143-00-0	205-577-4	Dodecyl hydrogen sulfate;2-(2-hydroxyethylamino)ethanol	Alkylsulfate	Solberg: US20080196908
151-21-3	205-788-1	Sodium dodecyl sulphate	Alkylsulfate	Fire Services Plus: FireAde; FireAde AR AFFF
2235-54-3	218-793-9	Ammonium alkyl ether sulphate	Alkylsulfate	Kempartner AB: Unifoam, Unifoam S
25882-44-4	247-310-4	disodium;4-[2-(dodecanoylamino)ethoxy]-4-oxo-3-sulfonatobutanoate	Alkylsulfate	Angus Fire (Angus International: Angus Fire, National Foam and Eau et Feu.) : Expandol (aka Expandol 1-3), Expandol LT (aka Expanol 1-3LT)
273-257-1	68955-19-1	Sulfuric acid, mono-C12-18-alkyl esters, sodium salts	Alkylsulfate	N/A (identified via ECHA's dissemination website)
287-809-4	85586-07-8	Sulfuric acid, mono-C12-14-alkyl esters, sodium salts	Alkylsulfate	N/A (identified via ECHA's dissemination website)
3088-31-1	221-416-0	Sodium 2-(2-dodecyloxyethoxy)ethyl sulphate	Alkylsulfate	Buckeye Fire Equipment Company: Buckeye High Expansion Foam (BFC-HX) (aka Hi-Ex 2.2)

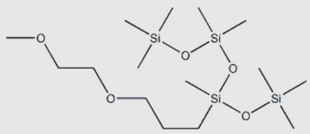
CAS	EC	Substance name	Chemical group	Supplier and Product Name
577-11-7	209-406-4	1,4-bis(2-ethylhexoxy)-1,4-dioxobutane	Alkylsulfate	Dr Sthamer: STHAMEX® K 1% F-15 #9143
68081-96-9	268-364-5	Sulfuric acid, mono-C10-16-alkyl esters, ammonium salts	Alkylsulfate	Orchidee Fire: Orchidex BlueFoam 3x3 Verde Environmental Inc (Micro Blaze): Micro-Blaze Out
68439-57-6	931-534-0, 270-407-8	Sulfonic acids, C14-16-alkane hydroxy and C14-16-alkene, sodium salts	Alkylsulfate	Dafo Fomtec AB: Enviro 3x3 Plus, Enviro 3x6 Plus, Environ 6x6 Plus Dr Sthamer: STHAMEX® 3% F6 Multi-purpose detergent foam, STHAMEX® K 1% F-15 #9143 vaPUREx LV 1% F-10 #7141
68877-55-4	272-563-2	Sodium 3-[2-(2-heptyl-4,5-dihydro-1H-imidazol-1-yl)ethoxy] propionate	Alkylsulfate	OneSeven of Germany GmbH: OneSeven ® Foam Concentrate Class B-AFFF, OneSeven ® Foam Concentrate Class B-AFFF-AR
68877-55-4	272-563-2	Sodium 3-[2-(2-heptyl-4,5-dihydro-1H-imidazol-1-yl)ethoxy] propionate	Alkylsulfate	OneSeven of Germany GmbH: OneSeven ® Foam Concentrate Class B-AFFF, OneSeven ® Foam Concentrate Class B-AFFF-AR
68891-38-3	500-234-8	Sodium laureth sulfate	Alkylsulfate	Angus Fire: Expandol (aka Expandol 1-3), Expandol LT (aka Expanol 1-3LT), Respondol ATF 3-6% Dafo Fomtec AB: Enviro 3% ICAO, Enviro USP, LS xMax, Trainer E-lite
85338-42-7	286-718-7, 939-332-4	Sulfuric acid, mono-C8-10 (even numbered)-alkyl esters, sodium salts	Alkylsulfate	Angus Fire: Respondol ATF 3-6% Dafo Fomtec AB: Enviro 3x3 Ultra, LS aMax
85665-45-8	939-262-4	Sulfuric acid, mono-C8-14 (even numbered)-alkyl esters, compds. with triethanolamine	Alkylsulfate	Dr Sthamer: MOUSSOL®–FF 3/6 F-15 #7941, MOUSSOL®–FF 3/6 F-5 #7942, STHAMEX® 2% F6 Multi-purpose detergent foam, STHAMEX-SV/HT 1% F-5 #9142, TRAINING FOAM-N 1% F-0 #9141

CAS	EC	Substance name	Chemical group	Supplier and Product Name
90583-18-9	939-265-0, 292-216-9	Sulfuric acid, C12-14 (even numbered)-alkyl-esters, compds. with triethanolamine	Alkylsulfate	Dafo Fomtec AB: Enviro 3% ICAO, Enviro USP OneSeven of Germany GmbH: OneSeven Foam Concentrate Class A vs FOCUM: Silvara APC 3x6 Unifoam Bio Yellow
90583-25-8	292-224-2	Sulfuric acid, mono-C6-12-alkyl esters, sodium salts	Alkylsulfate	
N/a	919-131-8	Fatty alcohol polyglycol ether sulfate, sodium salt	Alkylsulfate	BASF: Emulphor® FAS 30
N/a	944-611-9	Reaction mass of C-isodecyl and C-isoundecyl sulphonatosuccinate	Alkylsulfate	Respondol ATF 3-6%
4292-10-8	224-292-6	(carboxymethyl)dimethyl-3-[(1-oxododecyl)amino]propylammonium hydroxide	Detergent	vs FOCUM: Silvara 1 (1%), Silvara ZFK (0.5%)

Siloxanes

A limited number of siloxanes were identified in this task, this might be because the usage of this substance group is still in the phase of development. This is further explained in the following. Only one substance belonging to siloxanes could be identified by CAS number. This substance is a mixture of siloxanes and silicones (CAS 117272-76-1). It was found in products by Denko, namely: 1% AFFF; 3% AFFF; 6% AFFF; Alcohol AFFF 3% - 6% Single or Double Strength. Judging by the name, it could be that these substances were used in combination with fluorinated substances. However, for the sake of completeness the substance is named although it is not used as a PFAS-replacement. This information is shown in the table below, where also the chemical structure is shown.

Table 3.3 Siloxanes (identified by CAS) incl. CAS/EC identifier, the substance name, chemical group and the supplier and/or product name

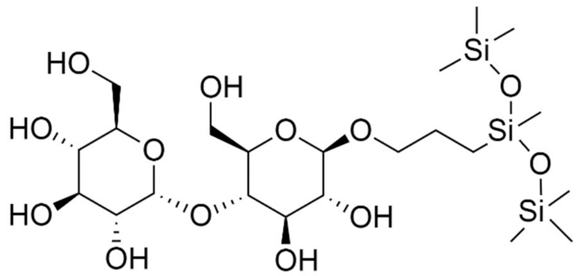
CAS	EC	Substance name	Chemical group	Supplier & Product Name	Chemical structure
117272-76-1	601-468-4	Siloxanes and Silicones, 3-hydroxypropyl Me, ethers with polyethylene glycol mono-Me ether	Siloxanes	1% AFFF Denko 3% AFFF Denko 6% AFFF Denko Alcohol AFFF 3% - 6% Single or Double Strength Denko	

In addition, publications by Hetzer et al. presented various sugar-based siloxanes for which CAS-numbers are not available. For a better understanding, in Figure 3.2 a sugar-based siloxane, as presented by Hetzer et al., is shown. It is important to note that these substances are used without further addition of PFAS substances.

The most recent publication by these researchers states that siloxane-based firefighting foam concentrate shows an extinguishing performance which significantly surpasses the commercial PFAS-free foams (whereby the actual product is not named) and nearly meets the performance of the PFAS-containing AFFF in fire suppression tests based on the NATO standard fuel F-34 (class B fire). However, no commercial product containing these substances was identified in this task.

Regarding their persistency, some siloxanes are known SVHC, having identified PBT and/or vPvB properties (cyclic D4, D5, D6) and others (linear) are currently undergoing PBT-assessment (e.g. octamethyltrisiloxane). In this context, the publications highlight that the formation of the desired product and its purity were verified after the filtration process. No more information is available at this time.

Figure 3.2 Sugar-based siloxane as described by Hetzer et al.



For more information on these substances please refer to the individual publications (Hetzer, R. et al. ; Hetzer, R. et al. 2014; Hetzer, R. H. und Kümmerlen 2016; Hetzer, R. H. et al. 2015).

Proteins

Regarding protein-based foams also only one substance with a CAS number could be identified. This belongs to silk-based protein hydrolysate (CAS 306-235-8). However, the associated product/foam manufacturer was not identified. Some SDS mention proteins from horn and hoof (National Foam) or hydrolysed protein (Gepro Group PROFOAM 806G). In these cases, no CAS number was given. The sources mentioning horn and hoof-based proteins also recommended that these should not be used because of the risk of epizootic diseases.

Task 1.3: Substance identification - PFAS

Generally, most information on PFAS in fire-fighting foams was found in the scientific literature. This is partially due to the fact that SDS and supplier information only indicate general terms like “fluorinated surfactant” without naming a CAS number and/or referring to propriety information. Environmental agencies mostly also cite scientific literature, so this information overlaps with substances already identified in the review of scientific literature. This is also true for information from legislation (REACH, Stockholm, Basel Convention).

When searched in pubmed and google scholar, the following search terms were used:

("fluorochemical" OR "per- and polyfluoroalkyl" OR "perfluoroalkyl" OR "polyfluoralkyl" OR "fluorinated" OR "PFAS") AND ("fire fighting" OR "airport" OR "fire")*

As of April 2019, this search yielded 86 hits. Those publications were mostly highly relevant, and the substance details were extracted into excel sheets relevant for the next working steps.

An additional source of information is case studies and monitoring activities. However, these are considered to be of less importance because mostly only a very limited variety of PFAS substances was covered.

Additionally, when environmental/human samples are considered, for fluorinated foams, also environmental and biological degradation processes need to be considered. For example, it is known that perfluorosulfonamides, undergo abiotic degradation as well as in vivo and in vitro biotransformation (DanEPA 2015).

With regards to the substances identified in the scientific literature, for a large share it was not possible to find a CAS/EC number. Sixty-three substances were identified by CAS/EC number, while around 213 were only identified by substance name/structure. This lack of CAS numbers may be due to the fact that those substances have been described for the first time by the respective author or are perhaps polymeric substances that do not necessarily have CAS numbers. In general, these numbers might also indicate that a lot of substances have been used that are currently poorly known.

The following information relates only to those substances that were fully identified in terms of CAS/EC, substance name and/or acronym.

Based on the CAS-identified PFAS-substances that were/are used in AFFF the following grouping is possible, indicated in brackets is the number of CAS-identified substances:

- Unsubstituted long chain PFAS (14);
- Unsubstituted short chain PFAS (8);
- Substituted short and long chain PFAS (12);
- Fluorotelomers (22); and
- Others (7).

Long Chain PFAS

The group of **long chain PFAS** (defined by OECD as perfluorosulfonic acids (PFSAs) with C≥6 and perfluorocarboxylic acids (PFCAs) with ≥ C8) encompasses the following substances:

PFSAs with ≥C6

- PFHxS (C6);
- PFHpS (C7);
- PFOS (C8);
- PFNS (C9);
- PFDS (C10); and
- PFUnDS (C11).

As can be seen in the table below, the identified sulfonic acids exhibit chain length up to 11 perfluorinated carbons.

Table 3.4 PFSAs (identified by CAS) with ≥C6 incl. CAS/EC identifier, the designation, the acronym and the supplier and/or product name

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
355-46-4	206-587-1	Perfluorohexane sulfonic acid	PFHxS	Ansul AFFF Ansulite® 3M LightWater Angus Fire, N/a Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan Angus Fire, 2007; Hi Combat A ™ 3M, 2005; ATC-603 Light water ATC3 3M, 1999; FC-203FC Light water Brand AFFF 3M 1999 3M 1992 3M 1993 3M 1998 (slightly different shares) 3M 1989 3M 1988
375-92-8	206-800-8	perfluoroheptane sulfonic acid	PFHpS	3M 1992 3M 1993 3M 1998 (slightly different shares) 3M 1989 3M 1988
1763-23-1	217-179-8	Perfluorooctanesulfonic acid	PFOS	3M AFFF ("PFSAs have been components of 3M AFFF from the 1970s to 2001") 3M LightWater FC-203FC 3M, 2005; ATC-603 Light water ATC3 3M, 1999; FC-203FC Light water Brand AFFF 3M 1992 3M 1993 3M 1998 (slightly different shares) 3M 1988 3M 1989 Ansul Ansulite® AFFF Angus Fire, N/a Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan Angus Fire, 2007; Hi Combat A ™ Hazard Control Technologies, Inc., 2003 F-500 Dr. Sthamer STHMEX-AFFF 3%
68259-12-1	N/a	Perfluoronone sulfonic acid	PFNS	3 M Lightwater PFSAs have been components of 3M AFFF from the 1970s to 2001
335-77-3	206-401-9	Perfluorodecanesulfonic acid	PFDS	3M Ansul AFFF Angus Fire, N/a Fomtec MB 5
749786-16-1	N/a	Perfluoroundecan sulfonic acid	PFUnDS	No product/supplier is mentioned; Publications are based on environmental samples

The identified PFCAs encompass the following substances:

PFCAs with ≥C8:

- PFOA (C8);
- PFNA (C9);
- PFDA (C10);
- PFUnDA (C11);
- PFDoDA (C12);
- PFTrDA (C13);
- PFTeDA (C14); and
- PFOcDA (C18).

The carboxylic acids exhibit chain length up to 18 perfluorinated carbons. All of the substances were identified in various "old" products (newest product is from 2007) from different manufacturers. This can be seen in the table below.

Table 3.5 PFCAs (identified by CAS) with ≥C8 incl. CAS/EC identifier, the designation, the acronym and the supplier and/or product name

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
335-67-1	206-397-9	Perfluorooctanoic acid	PFOA	Ansul AFFF Ansulite® 3M LightWater Angus Fire, N/a Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan 3M, 2005; ATC-603 Light water ATC3 3M, 1999; FC-203FC Light water Brand AFFF 3M 1999 3M 1992 3M 1993 3M 1998 (slightly different shares) 3M 1989 3M 1988 OneSeven B-AR ARC Miljö Towalex plus Towalex 3x3 Towalex 3% super Towalex 3% master Sthamex AFFF-P 3% FC-203FC Light Water 3M
375-95-1	206-801-3	Perfluorononanoic acid	PFNA	Ansul AFFF Ansulite® 3M LightWater Angus Fire, N/a Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan OneSeven B-AR ARC Miljö Towalex 3x3 Towalex 3% master Hazard Control Technologies, Inc., 2003 F-500

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
335-76-2	206-400-3	Perfluorodecanoic acid	PFDA	Ansul AFFF Ansulite® 3M LightWater 3M FC-203FC Light Water Fomtex Arc 3x3 Towalex plus Towalex 3x3 Towalex 3% master
2058-94-8	218-165-4	Perfluoroundecanoic acid	PFUnDA	3M LightWater 3M LightWater FC-203FC Ansul Ansulite® ANSUL Ansulite 6 % AFFF (Formula 1559-22 ICAO-B)
307-55-1	206-203-2	Perfluorododecanoic acid	PFDoDA	Ansul AFFF Ansulite® 3M LightWater Sthamex F-15 Towalex 3% master
72629-94-8	276-745-2	Perfluorotridecanoic acid	PFTrDA	PFCAs were primary components in early 3M AFFFs from 1965 up to 1986
376-06-7	N/a	Perfluorotetradecanoic acid	PFTeDA	3M AFFFs from 1965 up to 1987 Ansul AFFF FC-203FC Light Water 3M
16517-11-6	240-582-5	Perfluorostearic acid	PFODA	No product/supplier is mentioned; Publications are based on environmental samples

Short chain PFAS

Short chain PFAS were also identified in this study, namely:

PFSAs with C<6:

- PFEtS (C2);
- PFPrS (C3);
- PFBS (C4); and
- PFPeS (C5).

The list below shows that the identified sulfonic acids cover chain lengths from C2-C5.

Table 3.6 PFSAs (identified by CAS) with <C6 incl. CAS/EC identifier, the designation, the acronym and the supplier and/or product name

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
354-88-1	N/a	Perfluoroethane sulfonic acid	PFEtS	3M AFFFs Shorter chains C2-C3 PFSAs used in from 1988 to 2001
423-41-6	N/a	Perfluoropropane sulfonic acid	PFPrS	3M AFFFs Shorter chains C2-C3 PFSAs used in from 1988 to 2001

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
375-73-5	206-793-1	Perfluorobutanesulfonic acid	PFBS	Ansul AFFF Ansulite® 3M LightWater Angus Fire, N/a Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan Angus Fire, 2007; Hi Combat A ™ 3M, 2005; ATC-603 Light water ATC3 3M, 1999; FC-203FC Light water Brand AFFF 3M 1999 3M 1992 3M 1993 3M 1998 (slightly different shares) 3M 1989 3M 1988
2706-91-4	220-301-2	Perfluoropentane sulfonic acid	PFPeS	No product/supplier is mentioned; Publications are based on environmental samples

Also carboxylic acids have been identified. Contrary to the sulfonic acids, the carboxylic acids were only found starting from C4.

PFCAs with < C8:

- PFBA (C4);
- PFPeA (C5);
- PFHxA (C6); and
- PFHpA (C7);

In the table below, the short chain PFCAs are shown.

Table 3.7 PFCAs (identified by CAS) with <C8 incl. CAS/EC identifier, the designation, the acronym and the supplier and/or product name

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
375-22-4	206-786-3	perfluoro-n-butanoic acid	PFBA	Ansul AFFF Ansulite® 3M LightWater Angus Fire, N/a Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan Angus Fire, 2007; Hi Combat A ™ 3M, 2005; ATC-603 Light water ATC3 3M, 1999; FC-203FC Light water Brand AFFF OneSeven B-AR ARC Miljö Towalex 3x3 Towalex 3% master Sthamex AFFF-P 3%

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
2706-90-3	220-300-7	Perfluoropentanoic acid	PFPeA	3M LightWater FC-203FC 3M 1999 3M 1992 3M 1993 3M 1998 (slightly different shares) 3M 1989 3M 1988 Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan Ansul AFFF Ansulite®
307-24-4	206-196-6	Perfluorohexanoic acid	PFHxA	Ansul AFFF Ansulite® 3M LightWater Angus Fire, N/a Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan 3M, 2005; ATC-603 Light water ATC3 3M, 1999; FC-203FC Light water Brand AFFF 3M 1999 3M 1992 3M 1993 3M 1998 (slightly different shares) 3M 1989 3M 1988 OneSeven B-AR ARC Miljö Towalex plus Towalex 3x3 Towalex 3% super Towalex 3% master Sthamex AFFF-P 3%
375-85-9	206-798-9	Perfluoroheptanoic acid	PFHpA	Ansul AFFF Ansulite® 3M LightWater Angus Fire, N/a Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan Angus Fire, 2007; Hi Combat A ™ Angus Fire, 2004 Tridol S 3 % 3M, 2005; ATC-603 Light water ATC3 3M, 1999; FC-203FC Light water Brand AFFF FC-203FC Light Water 3M OneSeven B-AR ARC Miljö Towalex 3x3 Towalex 3% master Sthamex AFFF-P 3%

In general, both short and long chain PFAS were identified as substances used in AFFF. One author highlights that PFCAs were primary components in early 3M AFFFs from 1965 up to 1986 (Barzen-Hanson und Field 2015).

Derivates of perfluoroalkyl sulfonic PFAS (also PASF-based substances)

All the named substances above are characterized by a perfluorinated alkaline carbon chain that is connected to a sulfonic- or carboxylic acid head group. In other PFAS substances, this head group is also equipped with additional chemical groups. This group is also called perfluroalkane sulfonyl fluoride substances (PASF), as their synthesis is based on perfluroalkane sulfonyl fluoride. This can be for example an amide (sometimes methylated or ethylated). The chemical formulae of this group can be summarised as:

- Perfluoroalkane sulfonyl fluoride (PASF) = $C_nF_{2n+1}SO_2F$; and
- PASF-based derivates = $C_nF_{2n+1}SO_2$-R, where R = NH, $NHCH_2CH_2OH$, etc.

However, in most cases, these substances were not found when the actual foam was tested but rather when environmental samples were tested. In addition, some of the substances are also known to be environmental transformation products. Other substances are raw materials for surfactant and surface protection products (EtFOSE and N-MeFOSe) (Buck et al. 2011). In this sub group, the following substances were found:

- PFOSaAm;
- C7-FASA (PFHpSA);
- C8-PFSiA (PFOSI);
- EtFOSAA;
- EtFOSE;
- FBSA;
- FOSA;
- FOSAA;
- FOSE;
- N-MeFOSA;
- N-MeFOSE;
- PFBSaAm;
- N-[3-(Dimethyloxidoamino)propyl] -3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluor-1-octanesulfonamid; and
- (Carboxymethyl)dimethyl [3- (gamma-omega-perfluor-1-C6-14-Alkansulfonamid)propyl)ammonium.

In addition, some of those compounds are known PFOS-precursors (for example PFOSaAm, EtFOSAA, PFOSI, EtFOSE).

Table 3.8 Identified derivates of perfluoroalkyl sulfonic PFAS (also PASF-based substances)

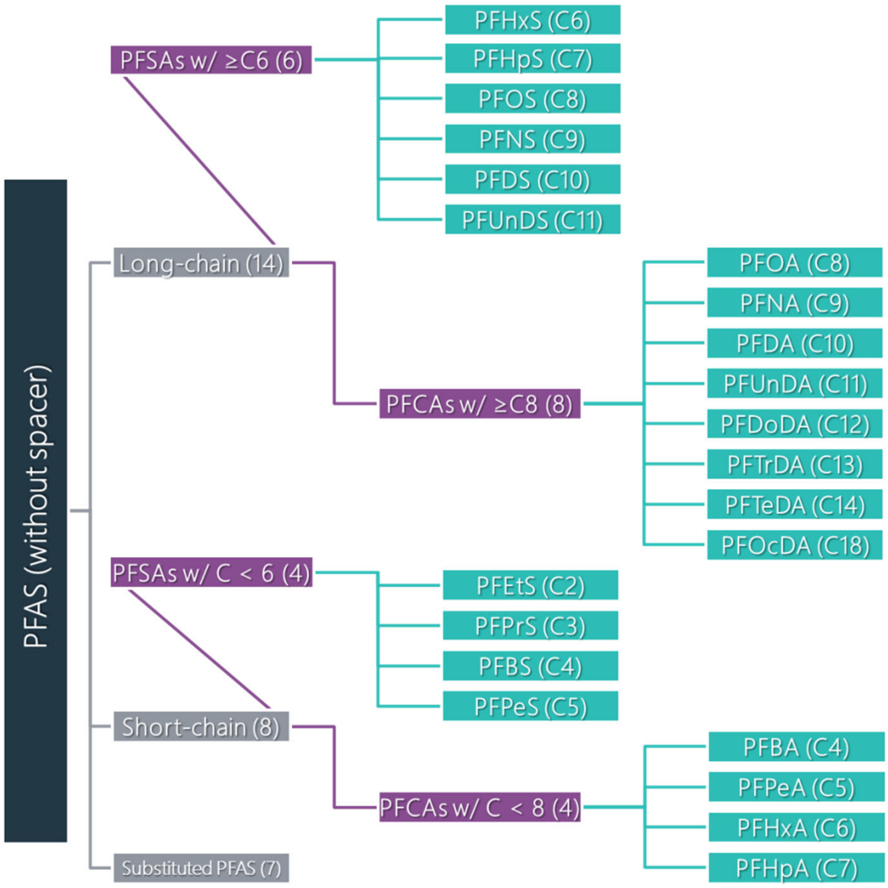
CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
13417-01-1	236-513-3	PPerfluoroalkyl sulfonamido amines	PFOSaAm	National Foam ; Ansulite; 3M lightwater; 3M
167398-54-1	N/a	Perfluoroheptane sulfonamidoethanol	C7-FASA (PFHpSA)	3 M Lightwater was used from 1988 until 2001 OR Ansul (telomer-based foam)

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
647-29-0	N/a	N/a	C8-PFSiA (PFOSI)	3M 1988 3M 1989
2991-50-6 / 1336-61-4	221-061-1	N-Ethyl perfluorooctane sulfonamidoacetic acid	EtFOSAA	No product/supplier is mentioned; Publications are based on environmental samples
4151-50-2	223-980-3	N-Methyl perfluorooctane sulfonamidoacetic acid	EtFOSE	No product/supplier is mentioned; Publications are based on environmental samples
68298-12-4	N/a	N-Methylperfluorobutanesulfonamide	FBSA	No product/supplier is mentioned
2806-24-8	N/a	perfluorooctane sulfonamido acetic acid	FOSAA	No product/supplier is mentioned; Publications are based on environmental samples
754-91-6	212-046-0	Perfluorooctane sulfonamide	FOSA	No product/supplier is mentioned; Publications are based on environmental samples
10116-92-4	N/a	N/a	FOSE	No product/supplier is mentioned; Publications are based on environmental samples
2355-31-9	N/a	N-methyl perfluorooctanesulfonamidoacetic acid	N-MeFOSA	No product/supplier is mentioned; Publications are based on environmental samples
24448-09-7	246-262-1	N-Methyl perfluorooctane sulfonamidoethanol	N-MeFOSE	No product/supplier is mentioned; Publications are based on environmental samples
68555-77-1	271-455-2	perfluoroalkyl sulfonamido amines	PFBSaAm	No product/supplier is mentioned; Publications are based on environmental samples
80475-32-7	279-481-6	N-[3-(Dimethyloxidoamino)propyl] -3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluor-1-octanesulfonamid	N/a	Dupont, Forafac® 1183

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
133875-90-8	N/a	(Carboxymethyl)dimethyl [3- (gamma-omega-perfluor-1-C6-14-Alkansulfonamid)propyl)ammonium (inneres Salz)	N/a	Dupont, Forafac® 1203

In addition to the tables above, the identified substances and their respective chemical relationship can be visualised in terms of a hierarchical clustering. This is shown in the figure below.

Figure 3.3 Hierarchical clustering of the identified short-, long-chain and substituted PFAs substances



Fluorotelomers

Fluorotelomers are defined by having an additional non-fluorinated spacer between the perfluorinated alkyl chain and the charged head group (denotated as number of perfluorinated carbons: number of non-fluorinated carbons). The fully identified substances (i.e. by CAS/EC number) are shown in Table 3.9.

As shown in the table below, the 22 identified fluorotelomers cover a wide range of positively/negatively charged head groups or combinations of those. Most of the fully identified substances, exhibit the xx:2 structure, where two non-fluorinated carbon atoms are inserted between the perfluorinated carbon chain and the head group. However, in the case of fluorotelomer betaines also xx:1:2 and xx:3 are found. In the latter case, three non-fluorinated carbon atoms are inserted between the perfluorinated carbon chain and the head group. In the case of the xx:1:2 substances, an additional fluorinated carbon is inserted between the perfluorinated alkyl chain and the non-fluorinated spacer.

Based on the manufacturing dates that are cited in the respective publications, it can be assumed that the use of fluorotelomers in fire-fighting foams began later than the use of traditional PFAS substances without a non-fluorinated spacer.

The following head groups have been identified:

- Alkylbetaine (AB);
- Betaine (B);
- Carboxylic acid (CA);
- Hydroxy (OH);
- Thioamido sulfonates (TAoS);
- Unsaturated carboxylic acid (UCA);
- Sulfonamido betaines (SaB);
- Sulfonamide amine (SaAm); and
- Thio hydroxy ammonium (THN+).

Table 3.9 Fluorotelomer (identified by CAS) substances incl. CAS/EC identifier, the designation, the acronym and the supplier and/or product name

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
34455-35-1	N/a	10:2 Fluorotelomer sulfonamide alkylbetaine	10:2 FTAB	F-500, Hazard Control Tech., 1997 National Foam 2005 National Foam 2007 National Foam 2008 Fire Service Plus AFFF 2011 National Foam 2003-2008
53826-13-4	N/a	10:2 Fluorotelomer carboxylic acid	10:2 FTCA	No product/supplier is mentioned; Publications are based on environmental samples
70887-84-2	N/a	10:2 fluorotelomer unsaturated carboxylic acid	10:2 FTUCA	No product/supplier is mentioned; Publications are based on environmental samples
278598-45-1	N/a	Fluorotelomer sulfonamido betaines	12:2 FtSaB	3M Ansul, 2006 Ansul Anulite ARC

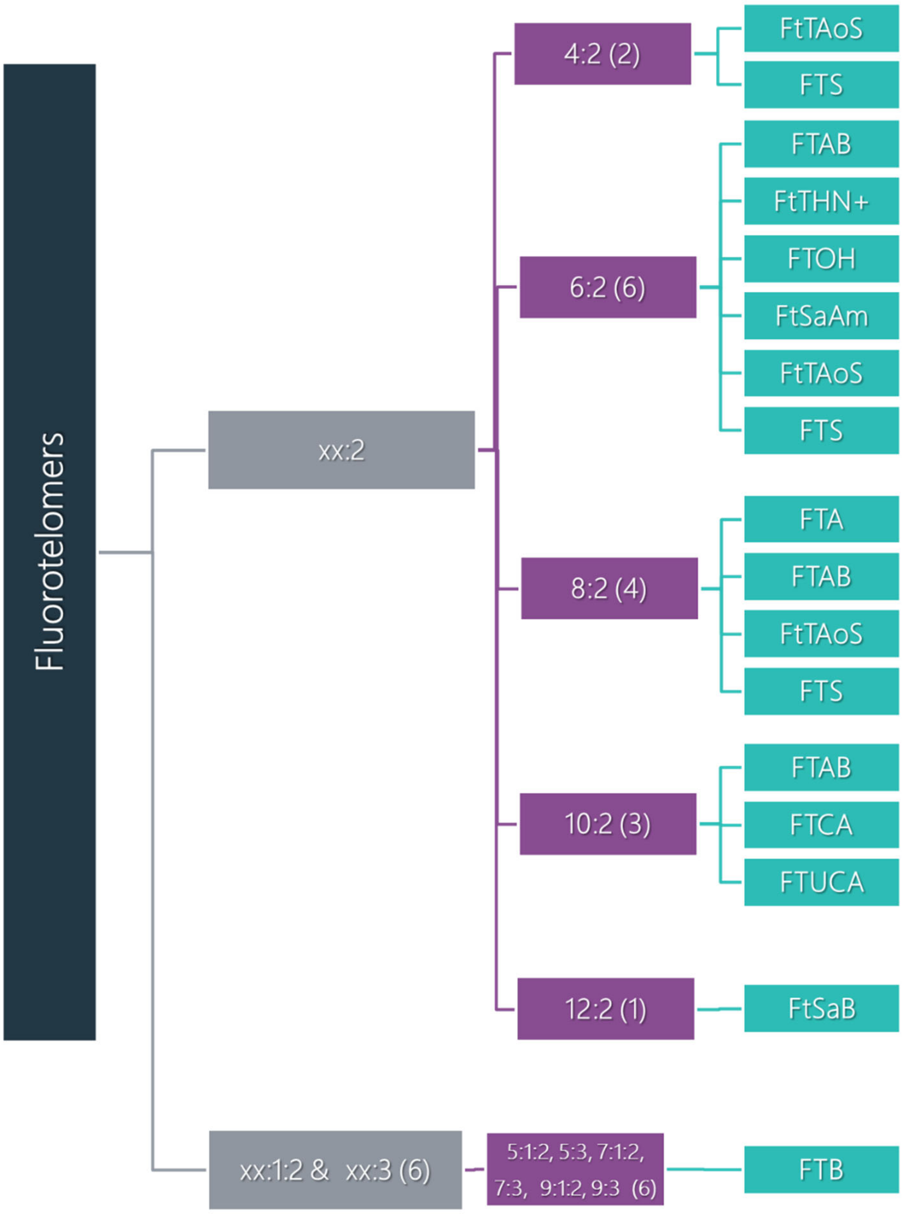
CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
757124-72-4	816-391-3	Fluorotelomer sulfonates	4:2 FTS	Angus Fire, 2004 Tridol S 3% Ansul 2002 Anslite 3% AFFF-DC-6 Hazard Control Tech 1197 F-500 National Foam
1432486-88-8	N/a	4:2 fluorotelomer thioamido sulfonates	4:2 FtTAoS	Ansul AFFF formulations Angus Fire, 2004 Tridol S Ansul, 2002 Ansulite 3% AFFF DC-3 Ansul, 2006 Ansul Anulite ARC Hazard Control Tech., 1997 F-500 Chemguard Ansul Angus
171184-02-4	N/a	5:1:2 fluorotelomer betaine	5:1:2 FTB	3M Ansul, 2002 Ansulite 3% AFFF DC-3 Buckeye 2009 Buckeye AFFF 2004
171184-14-8	N/a	5:3 fluorotelomer betaine	5:3 FTB	3M Buckeye
34455-29-3	252-046-8	6:2 Fluorotelomer sulfonamide betaine	6:2 FTAB	Chemours, STHAMEX® -AFFF 3% F-15 #4341 Dupont Forafac 1157 Dr. Sthamer, 3M National Foam F-500, Hazard Control Tech., 1997 (Foam 1) Angus Fire, 2004 Tridol S Angus Fire, 2000 Niagara 1-3 Chemours
647-42-7	211-477-1	6:2 Fluorotelomer alcohol	6:2 FTOH	No product/supplier is mentioned; Publications are based on environmental samples

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
27619-97-2	248-580-6	6:2 Fluorotelomer Sulfo nate	6:2 FTS	Dr. Richard Sthamer GmbH & Co. KG STHMEX-AFFF 3% Hazard Control Tech., 1997 F-500 Angus Fire, 2004 Tridol S 3 % Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan Angus Fire, 2004 Tridol S 3 % Ansul, 2002 Ansulite 3 % AFFF - DC-4 Ansul, 2006; Ansul Anulite ARC National Foam 2005 National Foam 2007 National Foam 2008 (slightly different shares)
1383438-86-5	N/a	6:2 fluorotelomer sulfonamide amine	6:2 FtSaAm	3M, National Foam 2005 National Foam 2007 National Foam 2008 (slightly different shares)
88992-47-6	N/a	6:2 fluorotelomer thioether amido sulfonic acid	6:2 FtTAoS	Angus Fire, 2004 Tridol S Ansul 1986 Ansul 1987 Angus Fire, 2000 Niagara 1-3 Ansul, 2002 Ansulite 3% AFFF DC-3 Ansul 2009 Ansul 2010 Chemguard 2008 F-500, Hazard Control Tech., 1997
88992-46-5	N/a	6:2 fluorotelomer thio hydroxy ammonium	6:2 FtTHN+	3M
171184-03-5	N/a	7:1:2 fluorotelomer betaine	7:1:2 FTB	3M Buckeye 2009
171184-15-9	N/a	7:3 fluorotelomer betaine	7:3 FTB	Buckeye Ansul, 2002 Ansulite 3% AFFF DC-3
27854-31-5	N/a	8:2 Fluorotelomer carboxylic acid	8:2 FTCA	F-500, Hazard Control Tech., 1997

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
34455-21-5	N/a	8:2 Fuorotelomer sulfonamide betaine	8:2 FTAB	National Foam, F-500, Hazard Control Tech., 1997 National Foam 2005 National Foam 2007 National Foam 2008 (slightly different shares) Fireade
39108-34-4	254-295-8	Fluorotelomer sulfonates	8:2 FTS	Ansul, 2002 Anslite 3 % AFFF - DC-5 Hazard Control Tech., 1997 F-500 Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan National Foam 2005 National Foam 2007 National Foam 2008
1383439-45-9	N/a	8:2 fluorotelomer thioamido sulfonates	8:2 FtTAoS	Chemguard, Ansul, 2006; Ansul Anulite ARC; Ansul, 2002 Ansulite 3% AFFF DC-3 Angus Fire, 2004 Tridol S Angus Fire, 2000; Niagara 1-3 Hazard Control Tech., 1997 F-500;
171184-04-6	N/a	9:1:2 fluorotelomer betaine	9:1:2 FTB	3M Buckeye AFFF 2004 Buckeye 2009
171184-16-0	N/a	9:3 fluorotelomer betaine	9:3 FTB	Buckeye 2009 3M 1988 3M 1989 3M 1993A 3M 1993B 3M 1998 3M 2001 Ansul, 2002 Ansulite 3% AFFF DC-3

In addition to this table, a hierarchical clustering was elaborated. This is shown in the figure below.

Figure 3.4 Hierarchical clustering of identified fluorotelomers



Other PFAS substances

In some cases, perfluorinated substances that do not belong to any of the named groups (long-/short-chain PFAS, fluorotelomers, and derivates of PFAS) were identified (**Others**). These substances are shown in the table below. Also shown below is the substance Dodecafluoro-2-methylpentan-3-one, a fluorinated ketone.

Figure 3.5 Chemical structure of Dodecafluoro-2-methylpentan-3-one, a fluorinated ketone

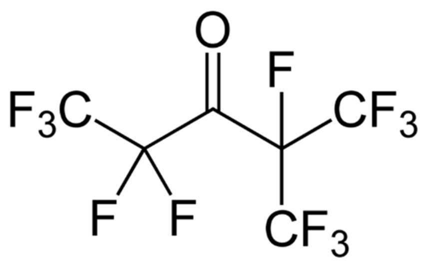


Table 3.10 Other per- or polyfluorinated substances (identified by CAS) incl. CAS/EC identifier, the designation, the acronym and the supplier and/or product name

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
1280222-90-3	480-310-4	ammonium 2,2,3 trifluor-3-(1,1,2,2,3,3-hexafluoro-3-trifluormethoxypropoxy) , propionate	ADONA	Mentioned in annex_xv_svhc_ec_206-397-9_pfoa_11549 as a substitute. However, no other source for this information.
756-13-8	616-243-6 / 436-710-5	Dodecafluoro-2-methylpentan-3-one	N/a	3M NOVEC TM 1230
161278-39-3	500-631-6	Poly(1,1,2,2-tetrafluoro-1,2-ethanediyl), α-fluoro-ω-2-[3-((carboxylatomethyl) dimethylammonio)propylaminosulfonyl]ethyl-	N/a	PROFOAM Profilm AFFF
70969-47-0	N/a	Thiols, C8-20, gamma-omega-perfluoro, telomers with acrylamide	Thiols, C8-20, gamma-omega-perfluoro, telomers with acrylamide	Towalex 3% master
70829-87-7	N/a	Sodium p-perfluorous nonenoxybenzene sulfonate	OBS	No product/supplier is mentioned; Publications are based on environmental samples
13269-86-8	236-267-7	Bis(trifluorovinyl)ether	N/a	Fire-extinguishing foam cited in Nordic working paper

Conclusions from task 1

In this substance identification process, three substance classes, that are/were used in firefighting foams, were considered: fluorine-free replacements, PFAS substances, and fluorinated but not-PFAS alternatives. The main outcomes of this task are as follows:

- For the latter substance class (fluorinated but not-PFAS alternatives) no substances were found, as also confirmed by experts;
- In the case of PFAS substances, various carboxylic/sulfonic short- and long chain PFAS were found. Additionally, also a variety of fluorotelomers. These substances differ in chain length and substitution and only a relatively small amount of these substances could be identified by CAS/EC number. Furthermore, other PFAS substances were found, that do not belong to any of the named PFAS-categories; and
- The identified fluorine-free PFAS-replacements can be grouped into four classes: hydrocarbons, detergents, siloxanes and proteins. For the latter two classes, the gathered information and the amount of identified substances are relatively small. In the case of the siloxanes, the usage of these substances in firefighting foams is still under development. In contrast to this, a variety of hydrocarbons (around 24) and detergents (33) were identified, that are used as a replacement for PFAS-substances.

In summary, a large number of highly diverse PFAS substances were found in the context of use in fire-fighting foams. This could be an indication of extensive replacement chemistry that was initiated due to industry and regulatory concerns about the potential health and environmental impacts of long-chain PFAS and lately also short-chain PFAS.

Chemical definitions of the identified substances which could be used for a possible future restriction

Any regulatory action on chemical substances/substance groups relies on a precise chemical identification. In the following the identified PFAS-substances have been checked to confirm whether they are covered by the general classification of per- and polyfluoroalkyl substances (PFASs) by the OECD, which itself is based on the commonly agreed terminology for nomenclature of PFASs (Buck et al. 2011).

In the case of the PFCAs, chemically defined as C_nF_{2n+1}-COOH, the substances identified in this task, AFFF-related PFAS-substances, would be covered. This is also true for the sulfonic homologues (PFSA, defined as C_nF_{2n+1}-SO_3H). Fluorotelomers-based substances are chemically defined by having a non-perfluorinated spacer between the perfluorinated carbon chain and a polar head group. The most known homologues of this subgroup are those that have a two carbon atom spacer (defined as C_nF_{2n+1}-C_2H_4-R). This definition is also given in the OECD report ("Working towards a global emission inventory of PFASs: focus on PFCAS - status quo and the way forward"). In this task, multiple substances belonging to this group were identified, varying in the perfluorinated chain length. However, homologues with a spacer of three non-fluorinated carbon atoms (for example 7:3 FTB) were also identified, thus the definition would need to be enlarged to C_nF_{2n+1}-C_mH_{m+1}-R, so that substance with a variable chain length could be included. In addition fluorotelomers with a non-fluorinated and an additional single-fluorinated carbon were identified (for example 7:1:2 FTB). In order to include such substances, the chemical definition for these homologues would need to be (C_nF_{2n+1}-CHF-C_mH_{m+1}-R).

The derivates of PFSA substances are chemically defined by having an additional chemical moiety connected to the sulfonic headgroup (C_nF2_{n+1}-SO_2-R). All of the identified substances identified in this task would be covered by this definition.

The identified substances grouped under the term "others" show diverse chemical structures. The only feature that is common to all of them is a perfluorinated substructure. However, in analogy to the perfluorinated ethers like ADONA (C_nF_{2n+1}-O- C_mF_{2m+1}), the substance Dodecafluoro-2-methylpentan-3-one (a ketone) could be defined by C_nF_{2n+1}-CO- C_mF_{2m+1}.

The following table summarises the named PFAS classifications, the generalised chemical structures, and the minimal number of carbon atoms of AFFF-related PFAS substances. It is observable, that the common sub unit is a perfluorinated ethyl-group (-C_2F_4- or -C_2F_5)[16]. Based on that, the definition that would be needed to be to cover the all relevant AFFF-related PFAS substances would be based on these particular -C_2F_4- or C_2F_5- sub groups.

Table 3.11 Overview of the PFAS classification, generalised chemical structures, and minimal number of C-atoms of substances that were identified as being used in AFFF

PFAS classification (Buck et al. 2011)	Generalised chemical structure	Minimal number of C-atoms as identified in AFFF
PFCAs	C_nF_{2n+1}-COOH	4
PFSAs I	C_nF_{2n+1}-SO_3H	2
PFSAs II	C_nF_{2n+1}-SO_2-R	4
Fluorotelomer-based substances I	C_nF_{2n+1}-C_2H_4-R	4
Fluorotelomer-based substances II	C_nF_{2n+1}-C_mH_{m+1}-R	4
Fluorotelomer-based substances III	C_nF_{2n+1}-CHF-C_mH_{m+1}-R	4
Perfluoroalkyl ether-based substances	C_nF_{2n+1}-O- C_mF_{2m+1}	2
Perfluoroalkyl ether-based substances	C_nF_{n+1}-CO- C_mF_{m+1}	2

In the following, a proposal for the definition in the form of substance identity, that could be used for a potential restriction, is made. For this, in the following table, the definition of PFOA as stated in the restriction (Entry 68 to Annex XVII to REACH) and a draft version of the possible definition for the restriction on PFAS-substances found in AFFF is shown. In addition, the definition in the "Information Document accompanying the "Call for evidence supporting an analysis of restriction options for the PFAS group of substances (fluorinated substance(s))" as published in the context of the RMOA has been used.

Table 3.12 Comparison of the substance identification as in the PFOA restriction and a proposal made for the PFAS-substances in AFFF.

Perfluorooctanoic acid (PFOA) CAS No. 335-67-1 EC No. 206-397-9 and its salts. Any related substance (including its salts and polymers) having a linear or branched perfluoroheptyl group with the formula C_7F_{15}- directly attached to another carbon atom, as one of the structural elements. Any related substance (including its salts and polymers) having a linear or branched perfluorooctyl group with the formula C_8F_{17}- as one of the structural elements.	Per- and polyfluoroalkyl substances (PFAS) CAS No. various EC No. various Any substance having at least two perfluorinated carbons with the formula $C_nF(2_{n+1})$- (n≥2) directly attached to any chemical group, as one of the structural elements. [This is a provisional definition that would need to be tested in terms of its implications as part of the consultation on any future restriction proposal, and

[16] -C_2F_4- if incorporated in the chemical structure of the PFAS substance or -C_2F_5 when attached terminaly to the structure.

The following substances are excluded from this designation: - C_8F_{17}-X, where X = F, Cl, Br. - C_8F_{17}-C(=O)OH, C_8F_{17}-C(=O)O-X′ or C_8F_{17}-CF_2-X′ (where X′ = any group, including salts).	taking into account the conclusions of the PFAS working group.]

In the following, the proposed definition is discussed in the context of whether it is comprehensive enough to avoid any existing or new PFAS being used in fire-fighting foams. For this the publicly available ECHA database has been checked using its advanced search feature based on structural elements.

Based on the proposed definition, any PFAS substance that contains $-C_nF_{2n+1}$ (n≥2) or $-C_nF_{n+1}$ (n≥2) as one of the structural elements would be covered. Substances with only one $-CF_3$ moiety would not be covered; however in this project no PFAS-substance with only a single-CF_3 moiety has been identified. In addtion, this group is used, for example, in certain drugs and pigments.

A fluorine to chlorine replacement is for example found in F-53B (6:2 chlorinated polyfluorinated ether sulfonate), a novel mist suppressant used as a replacement in metal plating (mainly in China see Du et al., 2016) . However, based on the entire structure this substance would also be covered by the definition proposed above.

1-Chloro-1,2,2,2-tetrafluoroethane (HCFC-124 , CAS No 2837-89-0) is a substance used in refrigerants as replacements for "older" chlorofluorocarbons. HCFC-124 is also used in gaseous fire suppression systems as a replacement for bromochlorocarbons. This particular substance would be not covered by the definition; however its potential usage in AFFF is questionable as it is gaseous. A search for this sub structure ($-CClF_3$ or (Cl)C(F)(F)F) gave nine hits. A search for bromine (Br)C(F)(F)F) resulted in three hits. The limited amount of hits, does, in a first approximation, show how many substances would not be covered by a possible restriction as elaborated above. However, the data is limited to the information publicly available in the ECHA database.

Also a replacement of fluorine atoms by hydrogen is observed in some substances (fluorotelomers). However, the fluorotelomers in this project would all be covered. An addtitional search in ECHA based on the $-CHF-CF_3$[17] substructure gave 15 hits.

Taken together, the proposed definition is very broad and should prevent existing or new PFAS being used in fire-fighting foams. However, when flouorine is replaced by, for example, chlorine, bromine or hydrogen, the resulting substances would not be covered.

It should be noted that this definition has been developed specifically in the context of fire fighting foams. This does not imply that it would be an appropriate definition for any other possible restriction on PFAS in other uses.

[17] SMILES (C(F)C(F)(F)F)

Bibliography for Section 3

Barzen-Hanson, K. A., Field, J. A. (2015): Discovery and Implications of C2 and C3 Perfluoroalkyl Sulfonates in Aqueous Film-Forming Foams and Groundwater. Environmental Science & Technology Letters, 2(4), 95-99.

Buck, R. C., Franklin, J. , Berger, U. , Conder, J. M., Cousins, I. T., de Voogt, P. , Jensen, A. A., Kannan, K. , Mabury, S. A. and van Leeuwen, S. P. (2011), Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. Integr Environ Assess Manag, 7: 513-541. doi:10.1002/ieam.258

Du, Z., Deng, S., Liu, D., Yao, X., Wang, Y., Lu, X.,Yu, G. (2016). Efficient adsorption of PFOS and F53B from chrome plating wastewater and their subsequent degradation in the regeneration process. Chemical Engineering Journal, 290, 405-413. doi:https://doi.org/10.1016/j.cej.2016.01.077

Harding-Marjanovic, K. C., Houtz, E. F., Yi, S., Field, J. A., Sedlak, D. L., Alvarez-Cohen, L. (2015): Aerobic Biotransformation of Fluorotelomer Thioether Amido Sulfonate (Lodyne) in AFFF-Amended Microcosms. Environmental science & technology, 49(13), 7666-7674.

Hetzer, R., Kümmerlen, F., Blunk, D. Auf dem Weg vom Siloxantensid zum fluorfreien AFFF.

Hetzer, R., Kümmerlen, F., Wirz, K., Blunk, D. (2014): Fire testing a new fluorine-free AFFF based on a novel class of environmentally sound high-performance siloxane surfactants. Fire Safety Science, 11, 1261-1270.

Hetzer, R. H., Kümmerlen, F. (2016): The Extinguishing Performance of Experimental Siloxane-Based AFFF.

Hetzer, R. H., Kümmerlen, F., Blunk, D. (2015). Fire Testing of Experimental Siloxane-Based AFFF: Results from New Experiments. Paper presented at the Conference Paper, Suppression, Detection and Signaling Research and Applications Symposium (SUPDET 2015), Orlando (Florida, USA).

ECD 2018: Toward a new comprehensive global database of per- and polyfluoroalkyl substances (PFASs): Summary report on updating the OECD 2017 List of per- and polyfluoroalkyl substances (PFASs). Available at: https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV-JM-MONO(2018)7&doclanguage=en

Wang, D. Z., Goldenman, G., Tugran, T., McNeil, A., & Jones, M. (2020). Per- and polyfluoroalkylether substances: identity, production and use. Retrieved from Copenhagen: https://doi.org/10.6027/NA2020-901. Available at: http://urn.kb.se/resolve?urn=urn:nbn:se:norden:org:diva-5872.

4. Task 2. Market analysis

4.1 Introduction

The main aim of this task is to estimate the tonnages of fluorine-based and fluorine-free fire-fighting foams manufactured and placed on the market in the EU. The different functions (e.g. film-forming, surfactants, solvents) provided by different components of fire-fighting foams and the type of fires for which their use is recommended is also discussed. In the following, the approach, in particular the specific literature sources and consultation responses contributing to this task, are briefly described. Then, the results are presented, outlining the available market information on PFAS in fire-fighting foams and their alternatives.

4.2 Approach

This task involved a combination of a targeted stakeholder consultation and a review of relevant literature and statistical sources.

Literature review

A literature review of information on tonnages of PFAS-containing and fluorinated fire-fighting foams has been conducted. This focused on keyword searches on google and a systematic review of information from key organisations in the field, including ECHA, UNEP, Emerging contaminants EU, Fire Industry Association and others, as well as companies active in the sector. The specific literature sources used are presented, along with the results, below.

Consultation

As discussed in Section 2, 33 stakeholders have provided written responses to the consultation questionnaire and several others have provided additional input following the study workshop. Of these, 26 have provided responses relevant to the market analysis.

Statistical sources

Relevant statistics providing quantities of production and trade of products in the EU have been screened, notably the Eurostat Prodcom database. However, the breakdown of the data in these sources is not sufficiently detailed to distinguish specific types of fire-fighting foams (or even foams from other fire-fighting preparations)[18].

[18] NACE codes are the statistical classification of economic activities (including production quantities and values of specific products) in the European Union. These were screened to identify relevant codes including fire-fighting foams. The most relevant code covers "Preparations and charges for fire-extinguishers; charged fire-extinguishing grenades" (code 20595250); however this does not distinguish between foams and other fire-fighting preparations, let alone different types of fire-fighting foams.

4.3 Results: PFAS in fire-fighting foams

Tonnages and values

Current status of knowledge in the literature

The information identified in the literature is shown in Table 4.1. Most of this data relates to amounts of PFOS or "PFOA-related compounds" specifically. However, according to information gathered in the framework of the Stockholm Convention[19] these long chain PFAS have already been increasingly (in the case of PFOS even completely) replaced by shorter chain PFAS for use in fire-fighting foams, so these data are likely out of date or only reflect a small share of the current market. Data on foams based on a wider range of PFAS has not been identified, except one figure: in 2015, 8,500 tonnes of fluorotelomers were used in fire-fighting foams globally[20]. The data is also presented in different ways, including quantity used, produced, in stock or purchased. Much of it relates to the EU or specific EU Member States, but some values for other countries are also shown, for reference.

[19] For PFOS: UNEP (2018) Draft report on the assessment of alternatives to perfluorooctane sulfonic acid, its salts and perfluorooctane sulfonyl fluoride, UNEP/POPS/POPRC.14/INF/8. For PFOA: UNEP (2018) Report of the Persistent Organic Pollutants Review Committee on the work of its fourteenth meeting - Addendum to the risk management evaluation on perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds, UNEP/POPS/POPRC.14/6/Add.2.

[20] FLUORINE-FREE FIRE-FIGHTING FOAMS (3F) - VIABLE ALTERNATIVES TO FLUORINATED AQUEOUS FILM-FORMING FOAMS (AFFF), White Paper prepared for the IPEN by members of the IPEN F3 Panel and associates, POPRC-14, Rome 17-21 September 2018.

Table 4.1 Overview of quantitative data from literature on the market of PFAS in fire-fighting foams

Location	Product	Quantity used for fire-fighting foam	Quantity produced	Quantity in stock for fire-fighting foam	Quantity purchased	Data year	Source	Original source
UK	PFOS	65 tonnes (16% of total)				2001	UNEP (2016) [1]	
Germany	PFOS	25 tonnes (87% of total)				2010	UNEP (2016) [1]	
Netherlands	PFOS-containing AFFFs			75% of the €25 million purchased still unused	€25,000,000 over 20 years	20 years up to 2009	Goldenman G. et al. (2019) [2]	RIVM (2009). Estimation of emissions and exposures to PFOS used in industry. Report 601780002/2009.
	PFOSF for manufacture of AFFFs		10,000 tonnes			In total from 1970 to 2002		
Europe	PFOA-related compounds	50-100 tonnes				2014	UNEP (2016) [1]	Annex XV Restriction Report — Proposal for a restriction substance name: PFOA, PFOA salts and PFOA-related substances, version 1.0 (German and Norwegian competent authorities). Available from: https://echa.europa.eu/documents/10162/e9cddee6-3164-473d-b590-8fcf9caa50e7
Europe	PFOA-related compounds (as impurities or constituents)	15-30 tonnes				2015	UNEP (2018) [6]	Report of the Persistent Organic Pollutants Review Committee on the work of its fourteenth meeting
Europe	"Fire-fighting foam (monomers)"	1.13-3.81 tonnes				unclear	Goldenman G. et al. (2019) [2]	Ministry of Infrastructure and Environment of Netherlands and Public Waste Agency of Flanders (2016). Inventory of awareness,

Location	Product	Quantity used for fire-fighting foam	Quantity produced	Quantity in stock for fire-fighting foam	Quantity purchased	Data year	Source	Original source
	(details unclear)							approaches and policy: Insight in emerging contaminants in Europe.
Europe	PFOS			90 tonnes		2011	UNEP (2016) [1]	
World	Fluoro-telomers		8,500 tonnes ("fire-fighting foams account for ~32% of the annual global tonnage of fluorotelomer production)			2015	IPEN (2018) [3]	"Global Markets Insights", 2016
Canada	PFOS-containing AFFFs			300 tonnes of fire-fighting foams, containing 3 tonnes of PFOS		2006	UNEP (2016) [4]	
Norway	PFOS-containing AFFFs			21 tonnes		2005	UNEP (2018) [5]	
Switzerland	PFOS-containing AFFFs			1,000 tonnes of fire-fighting foams, containing 10 tonnes of PFOS		2007	UNEP (2016) [4]	

Location	Product	Quantity used for fire-fighting foam	Quantity produced	Quantity in stock for fire-fighting foam	Quantity purchased	Data year	Source	Original source
China	PFOSF		200 tonnes			2006	UNEP(2016) [4]	
Japan	AFFF			19,000 tonnes		2016	UNEP(2016) [4]	

Sources:

[1] 'Pentadecafluorooctanoic acid (PFOA, Perfluorooctanoic acid), its salts and PFOA-related compounds DRAFT RISK PROFILE', UNEP-POPS-POPRC11CO, 2016

[2] Goldenman G. et al., 'The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS', 2019

[3] FLUORINE-FREE FIRE-FIGHTING FOAMS (3F) - VIABLE ALTERNATIVES TO FLUORINATED AQUEOUS FILM-FORMING FOAMS (AFFF), White Paper prepared for the IPEN by members of the IPEN F3 Panel and associates, POPRC-14, Rome 17-21 September 2018.

[4] Draft consolidated guidance on alternatives to perfluorooctane sulfonic acid and its related chemicals, UNEP-POPS-POPRC.12-INF-15.

[5] Report on the assessment of alternatives to perfluorooctane sulfonic acid, its salts and perfluorooctane sulfonyl fluoride, UNEP/POPS/POPRC.14/INF/13

[6] Report of the Persistent Organic Pollutants Review Committee on the work of its fourteenth meeting, UNEP-POPS-POPRC.14-6, 2018

Tonnages of fluorosurfactants used in fire-fighting foams production

According to data provided by Eurofeu, five foam manufacturers representing approximately 60-70% of the EU market purchase approximately 335 tonnes of fluorosurfactants per annum in the EU (data collected in 2018). These data include 7 specific known fluoro-compounds and 3 unknown fluoro-compounds (see Table 4.2). They are used to produce fire-fighting foam concentrates or liquid ready-for-use agents (pre-fill for fixed firefighting systems and/or portable extinguishers). According to the same Eurofeu data, the concentration of the fluoro-compound in the fire-fighting foam concentrates range between 0.1% and 45% (no average value was given).

It should be noted that the identity of the substances with the largest tonnages was not specified in these data as the data were confidential. Based on the approximate share of the market reflected in these data, it is estimated that the total tonnage of fluorosurfactants used in fire-fighting foams in the EU is approximately 480-560 tonnes per year[21]. This is consistent with the total tonnage of PFAS-based fire-fighting foams estimated further below, and an average concentration of fluorosurfactants in the foams of around 2-3% (as suggested by various stakeholder responses to the consultation).

Table 4.2 Tonnage of fluorosurfactants purchased for the production of fire-fighting foams by manufacturers participating in the 2018 Eurofeu survey

Fluoro-compound	CAS number	Tonnes per year	Share of the total market
1-Propanaminium,N-(carboxymethyl)-N,N-dimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulfonyl]amino]-,inner salt	34455-29-3	21.1	6%
1-Propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-N-[[(gamma-omega-perfluoro-C6-C16-alkyl)thio]acetyl] derives., inner salts	80475-32-7	17.2	5%
2-methyl-2 - [(1-oxo-3 - [(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl) thio] propyl) amino] -1-propanesulfonic acid, sodium salt	62880-93-7	0.5	<1%
2-hydroxy-N,N,N-trimethyl-3-[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)thio]-1-Propanaminium, chloride (1:1)	88992-45-4	0.2	<1%
2-Propenamide, telomer with 4-[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)thio]-1-butanethiol)	unknown	0.2	<1%
2-Propenoic acid, telomer with 2-propenamide and 4-[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)thio]-1-butanethiol, sodium salt	unknown	0.3	<1%
2-Propenamide, telomer with 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-1-octanethiol	76830-12-1	0.9	<1%
unknown C-6 fluorinated substances	unknown	17.1	5%
unknown 1	unknown	138.6	41%
unknown 2	unknown	138.6	41%

[21] According to Eurofeu, the data is expected to cover 60-70% of the EU market. The total market has been estimated by dividing 335 tonnes by 70% (lower end of range) and by 60% (upper end of range), respectively.

Fluoro-compound	CAS number	Tonnes per year	Share of the total market
Total (2018 Eurofeu survey)		335	
Total EU market (extrapolated)		480-560 [1]	

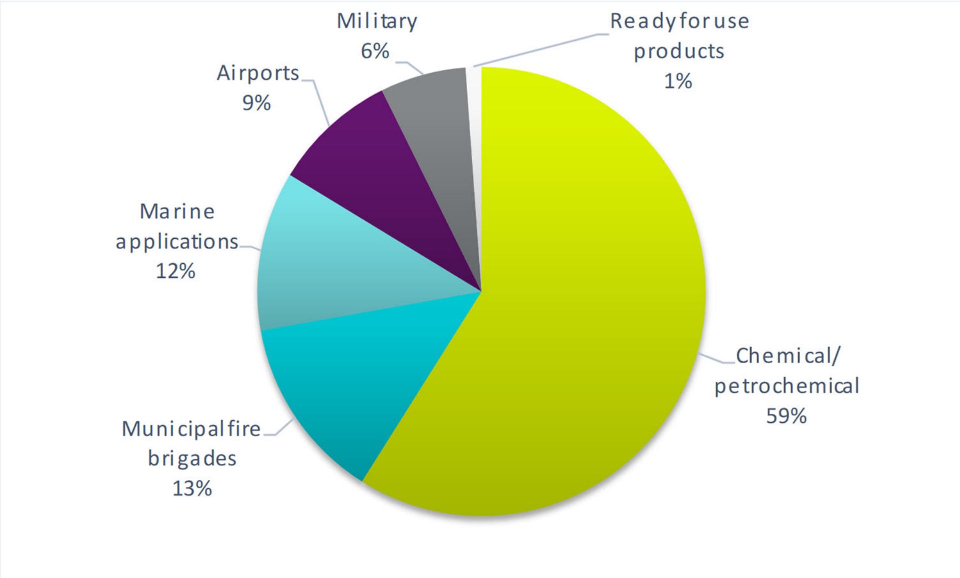
Source: Wood 2019 based on data provided to the authors by Eurofeu.
Notes:
Substances marked as unknown have not been revealed by the individual manufacturers to preserve commercially sensitive information.
[1] According to Eurofeu, the data is expected to cover 60-70% of the EU market. The total market has been estimated by dividing 335 tonnes by 70% (lower end of range) and by 60% (upper end of range), respectively. Results were rounded to two significant figures.

Sales of fire-fighting foams by user sector

Eurofeu also provided figures on the yearly sales of PFAS-based fire-fighting foams to various user sectors in Europe, based on a 3-year average (2016-2018). Six Eurofeu member companies[22] have provided data. In total, they sell 13,669 tonnes of PFAS-based fire-fighting foams per year. Of these, an estimated 8,200 are employed in fixed systems and 5,500 in mobile systems[23]. The split by sector is detailed in Figure 4.1 below. This shows that chemical/petrochemical is by far the largest user sector (59%), but municipal fire brigades, marine applications, airports and military applications also account for significant volumes[24]. Ready-for-use products only account for a very small share of PFAS-based foams according to this data. The majority of this category are fire extinguishers although not all foam fire extinguishers use ready-for-use foams, according to personal communications with Eurofeu). However, some stakeholders have suggested that the number of fire extinguishers using PFAS-based foams could be significant. An estimate is provided in the following sub-section.

[22] Dr. STHAMER Hamburg, Auxquimia (Perimeter Solutions), Solberg Scandinavia, Dafo Fomtec, Orchidee, Johnson Controls (aka Tyco)
[23] The number of companies that provided a response on whether the foams are used in fixed or mobile systems is lower than those that provided a response for the sectoral overview, therefore in the original data the total tonnage of the former is lower than the latter. To fill this gap, the tonnages for both fixed and mobile systems have been inflated so that their total matches the total in the sectoral split. The original values were 5.010 tonnes for fixed systems and 3,350 tonnes for mobile systems (total 8,360 tonnes).
[24] According to personal communication with Eurofeu, there is some uncertainty in the data available to foam manufacturers about the precise distinction between user sectors. This is because although certain products may be marketed primarily for a specific user sector, it is not always known to whom the products are ultimately sold through traders and vending companies, and what they ultimately use it for (particularly for large users active across several sectors). Generally "chemical/petrochemical" is expected to include offshore oil and gas platforms (in addition to refineries and other facilities storing, processing or transporting flammable liquids), while "marine applications" refers to the shipping industry. However, due to the above uncertainty some of the tonnage for marine applications may also reflect use in offshore oil and gas platforms.

Figure 4.1 Split of PFAS-based fire-fighting foams by sector



Source: Wood 2019 based on data provided to the authors by Eurofeu.

Eurofeu estimate that the data they provided based on an internal survey covers roughly 70% of the EU market. It is therefore estimated that the total annual EU use of PFAS-based fire-fighting foams could be in the order of 20 thousand tonnes[25].

Additional estimate of use in fire extinguishers

Three different sources for the number of fire extinguishers using PFAS-based fire-fighting foam in in the EU were identified:

1. Eurofeu provided the European Commission with a position paper which estimates that there are approximately 76 million fire extinguishers in the EU, approximately 15 million of which use PFAS-based fire-fighting agents;

2. Through individual communication with TSF (a German consultancy specialised in firefighting services), it has been estimated[26] that, in the whole of the EU, between about 60 million and 90 million fire extinguishers using PFAS-based foam currently exist, but note that this is a high-level estimate based on extrapolation from German data and expert judgement, so the Eurofeu estimate is likely more accurate; and

[25] Calculated as 13,669 tonnes divided by 70% and rounded to the closest thousand tonne.

[26] The values have been extrapolated from data from bvfa - Bundesverband Technischer Brandschutz e. V. (German Federal Association of Technical Fire Protection) for fire extinguisher sold in Germany in 2016 as follows. Tonnages of major additional fire extinguisher manufacturers that are not part of bvfa have been added to the bvfa data by TSF. This yields the estimate that approximately 2,2 million fire extinguishers are sold every year in Germany, with an average lifetime of 20-25 years, which suggests that roughly 50 million units are currently present in Germany. Dividing this figure by the German population (82 million), a value of 0.6 fire extinguishers per capita is obtained. This value is then multiplied by the population of each country to estimate the number of fire extinguishers in each of them (population Netherlands: 17 m, population France: 67 m, population Belgium: 11,5 m, population United Kingdom: 60 m, population Ireland: 5 m, population Austria: 9 m, population Switzerland: 8,5 m, population rest of Europe: 500 m). Finally, the value obtained is multiplied by the share of PFAS foam-based fire extinguishers on the total of fire extinguishers in each country as estimated by TSF (Germany: 35%, Netherlands: 55%, France: 55%, Belgium: 45%, United Kingdom: 25%, Ireland: 25%, Austria: 45%, Switzerland: 45%, rest of Europe: 10%). This yields the following number of fire extinguishers using PFAS-based foam per country: Germany: 17 million units; Netherlands: 6 million units; France: 22 million units; Belgium: 3 million units; United Kingdom: 10 million units; Ireland: 1 million units; Austria: 2 million units; Switzerland: 2 million units; Rest of Europe: 30 million units.

3. The REACH restriction proposal for PFHxA[27] states based on personal communication with one stakeholder and on data from the German Federal Association for Technical Fire Safety (bvfa), that in Germany roughly 600 000 hand held fire extinguishers containing AFFF are placed on the market per year, so it is possible that in Germany 6 - 12 million and EU-wide 40 - 80 million extinguishers are in use (i.e. in circulation in total rather than on an annual basis). Given the same underlying data source (bvfa) was used and similar results were obtained, it is likely that this is in fact the same estimation as source number 2 above, with slightly different assumptions.

Based on the figures above, the following estimates the total tonnage of PFAS-based fire-fighting foam in fire-extinguishers in circulation, as well as the annual tonnage placed on the market.

- The Eurofeu position paper quotes 6-9 litres as the typical size of a fire extinguisher. According to TSF (based on bvfa data), the size can range between 2 and 9 litres;
- Multiplication of 6-9 litres with the estimated 15 million fire extinguishers yields a range of 90-135 million litres (wider range: 30-810 million litres using 2-9 litres and 60-90 million fire extinguishers) of PFAS-based fire-fighting agents used in fire extinguishers. This would be equivalent to about 90,000-135,000 tonnes (wider range 30,000-810,000 tonnes)[28] of PFAS-based fire-fighting agents currently present in fire extinguishers in the EU, or ca 3,600-6,750 tonnes (wider range 1,200-35,000 tonnes) of PFAS-based fire-fighting agents sold in fire extinguishers in the EU annually[29]; and
- According to personal communication with Eurofeu, the PFAS-based fire-fighting agents in fire extinguishers are either foam concentrate already mixed with water, or a capsule of foam concentrate that is mixed with water when the extinguisher is triggered. That means that only a small share of the fire-fighting agent in the extinguisher is PFAS-based foam concentrate, and the concentration of PFAS in the fire-fighting agent is much lower (2-5g per 6-9 litre extinguisher, or 0.02-0.08%, according to the Eurofeu position paper) than for the foam concentrates discussed above. To make the 3,600-6,750 tonnes per year of PFAS-based fire-fighting agents in fire extinguishers comparable to sales of PFAS-based foam concentrates by sector (presented in the previous subsection), they need to be converted: Conservatively assuming that foam concentrates account for 10% of the fire-fighting agent for fire extinguishers would imply some 360-675 tonnes of PFAS-based foam concentrates are used annually in fire extinguishers in the EU28.[30]

Lastly, to sense check this result, it is compared to the tonnage of ready-for-use products estimated in the previous sub-section:

- Based on Eurofeu data, it was estimated that the total annual EU use of PFAS-based fire-fighting foams in the EU is at least 14,000 tonnes but it could be up to around 20,000 tonnes. Figure 4.1 (also based on Eurofeu data) puts the share of ready-for-use products at 1%, so the annual tonnage of ready-for-use products is around 140-200 tonnes.[31];
- This is somewhat lower than the estimated 360-675 tonnes of PFAS-based foam concentrates used in fire extinguishers. However, the data appear to be consistent because Eurofeu specified that not all foam fire extinguishers are included in the category "ready-for-use foams"; and

[27] https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18323a25d
[28] Assuming a density of approximately 1kg/l.
[29] Calculated by dividing the total tonnage present by the average lifetime of 20-25 years, as indicated by TSF.
[30] Calculated as: 3,600 tonnes of PFAS-based fire-fighting agents * 10% = 360 tonnes of PFAS-based foam concentrate. Similarly for the higher end of the range 6,750 tonnes * 10% = 675 tonnes.
[31] Calculated by multiplying the total tonnage of fire-fighting foams (14,000-20,000 tonnes) with the share of ready for use products (1%).

- Even if the share of ready-for-use products was higher than suggested by Eurofeu (Figure 4.1), the total tonnage across all sectors would not be significantly affected by the addition of a few hundred tonnes of ready-to-use products, as it was only estimated at an accuracy in the order of magnitude of thousands of tonnes in this report..

Other information on tonnages from the consultation

The following additional information on tonnages was provided in the consultation:

- Additional fire-fighting foam manufacturers (not covered by Eurofeu's internal survey) provided figures for three different products they manufacture where the PFAS Carboxymethyldimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propylammonium hydroxide (CAS number 34455-29-3) and 6:2 FTS are used (i.e. all three products use both substances combined). The three products are employed in different sectors:
  - The first is used by the respondents' customers in airport and marine applications. Of this foam, 700,000 litres are manufactured/imported and 200,000 litres are sold in the EU every year;
  - The second is used in oil and gas, marine, chemistry and municipal fire fighters applications. 450,000 litres of this product are manufactured/imported in the EU and 250,000 litres are sold every year in the EU;
  - The third product is used in the oil and gas and marine sectors. 250,000 litres of this foam are manufactured/imported and 100,000 litres are sold every year in the EU; and
  - These volumes are additional to the Eurofeu data presented above. The three foams in sum account for 550,000 litres of annual sales in the EU. Assuming a density of approximately 1kg/l, this would be equivalent to about 550 tonnes of foam that can be added to the Eurofeu total (but would already be included in the EU total extrapolated from Eurofeu data). Hover, given the exact sector split is not known, they have not been added to the sector breakdown.
- One respondent operating in the field of industrial safety, in particular dedicated to technical support and training, stated that they manufacture 5,000 litres per year of a foam containing a C6 fluorine compound, which is used only for training purposes. As above, this is additional to the Eurofeu data, but has not directly been added because the tonnage or density is not known;
- One respondent operating in the oil and gas sector provided figures for four fire-fighting foams they purchase; two of these contain poly(1,1,2,2-tetrafluoro-1,2-ethanediyl),alpha fluoro-omega-2-(3-((caboxylatomethyl)dimetylammonoi)propylaminosulfonyl)ethyl, whereas the other two contain different PFAS that have not been specified:
  - The two products containing poly(1,1,2,2-tetrafluoro-1,2-ethanediyl),alpha fluoro-omega-2-(3-((caboxylatomethyl)dimetylammonoi)propylaminosulfonyl)ethyl are used in the offshore oilrig and refinery sectors for spills[32], accidents and function tests in process plant fires and trainings. They purchase less than 5 tonnes per year of each of these foams and employ less than 5 tonnes in each instance of use;
  - The third product is used in the offshore oil and refinery sectors in cases of spills, accidents and function tests in alcohol fires. Similarly to the previous, less than 5 tonnes are bought every year and less than 5 tonnes are employed in each instance of use; and

[32] AFFF are in some cases also used as prevention in spills that have not (yet) caught fire. See for instance: https://www.nrl.navy.mil/accomplishments/materials/aqueous-film-foam

  - A volume between 30 tonnes and 70 tonnes of a fourth product is purchased every year by the respondent, but no other details have been provided regarding the use of this foam.

- One respondent operating in industrial safety for the oil refineries, chemicals and petrochemicals sectors provided figures for one foam based on the C6 fluorine compound, which is used for training exercises on large hydrocarbon fires. They purchase 5 tonnes per year of this product and typically employ it 100 days a year; and
- Another respondent operating in the oil refineries, chemicals and petrochemicals sectors provided figures for one product they purchase, which can be used for almost all class B fires. They purchase between 20 and 60 tonnes per year of this foam and in 75% of cases, fires are extinguished with less than 400 litres of foam concentrate.

Respondents quoted prices for PFAS based fire-fighting foams in the range from €2 to €30 per litre for concentrates. For those PFAS based fire-fighting foams for which data on tonnage and price is available, the weighted average price is around €3 per litre, but note that these products reflect only a small share of the total market, so this estimate is uncertain. Some consultation responses suggest that generally speaking, foams providing a higher performance often contain a higher concentration of PFAS which is associated with a higher cost.

Number of sites using fire-fighting foams

No specific data on the number of sites using fire-fighting foams (PFAS-based or fluorine-free) was available. However, in order to estimate the order of magnitude of user sites, the total number of sites in some of the main user sectors can be considered:

- Chemicals/petrochemicals: There are over 10,000 establishments covered under the EU's Seveso III Directive[33]. One of the main accident scenarios linked to most Seveso-regulated substances is related to fires. Many other facilities with flammable fuels and chemicals below the Seveso Directive thresholds will also require firefighting equipment;
- Marine applications: Over 1,200 commercial seaports operate in the EU[34] and Europe's maritime traffic is responsible for some 15,000 seagoing vessels[35];
- Airports: There are 401 commercial airports in the EU-28[36], many of which will have multiple fire-fighting foam storage/use equipment;
- Municipal fire brigades: There are over 50,000 public fire brigades in the EU, excluding those covering airports and private brigades covering industrial risks[37]; and
- Military: In the European Economic Area, there are about 239 military airbases.

Based on the above, there are likely to be several tens or potentially hundreds of thousands of facilities using (or at least possessing) fire-fighting foams. In addition, there are likely many other sites possessing fire-extinguishers using fire-fighting foams.

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[33] Analysis and summary of Member States' reports on the implementation of Directive 96/82/EC on the control of major accident hazards involving dangerous substances, Final report, https://op.europa.eu/en/publication-detail/-/publication/26c9aa63-523e-11e7-a5ca-01aa75ed71a1.

[34] European Commission (2013): Europe's Seaports 2030: Challenges Ahead. Available at : https://ec.europa.eu/commission/presscorner/detail/en/MEMO_13_448.

[35] In early 2019, the total world fleet stood at 95,402 ships. Europe accounted for 16% of container port traffic (as a proxy for the share of global vessels relevant to Europe). Source: UNCTAD Review of Maritime Transport 2019. Available at https://unctad.org/en/PublicationsLibrary/rmt2019_en.pdf.

[36] Eurostat: Number of commercial airports (with more than 15,000 passenger units per year) [avia_if_arp], Data for 2017.

[37] FEU statistics, https://www.f-e-u.org/career2.php

Conclusions

In conclusion, based on information provided by Eurofeu and additional manufacturers, it has been estimated that at least 14,000 tonnes, but probably around 20,000 tonnes of PFAS-based fire-fighting foams are sold in the EU annually. The main application is the chemical and petrochemical industry, which employs 59% of these foams. This is followed by municipal fire brigades, marine applications, airports and the military. The foams are used in fire incidents, spills, tests and training exercises.

There are likely several tens or potentially hundreds of thousands of facilities using (or at least possessing) fire-fighting foams, not counting those only using fire-extinguishers. Prices for PFAS based fire-fighting foams range from €2 to €30 per litre for concentrates, with the average estimated at around €3 per litre (subject to significant uncertainty).

Functions provided in the foams and types of fires the foams are used for

According to the consultation, the PFAS-based fire-fighting foams find application in a broad range of sectors, such as aviation, marine, oil and gas, offshore oil, refineries, chemicals and railways[38].

The main function of the PFAS contained in the foam is to act as a surfactant, i.e. to form a film over the burning liquid surface in order to prevent flammable gases from being released from it. This is a particularly relevant feature that enables applications in industrial fires - for example tank fires, where large quantities of flammable liquid are stored. They are used for training purposes and in a variety of fire incidents, from small fires to the above-mentioned large tank fires, and can be applied both with mobile and semi-stationary equipment.

4.4 Fluorine-free fire-fighting foams

Tonnages and values

Current status of knowledge in the literature

No information on tonnages and values of fluorine-free fire-fighting foams has been identified in the literature review.

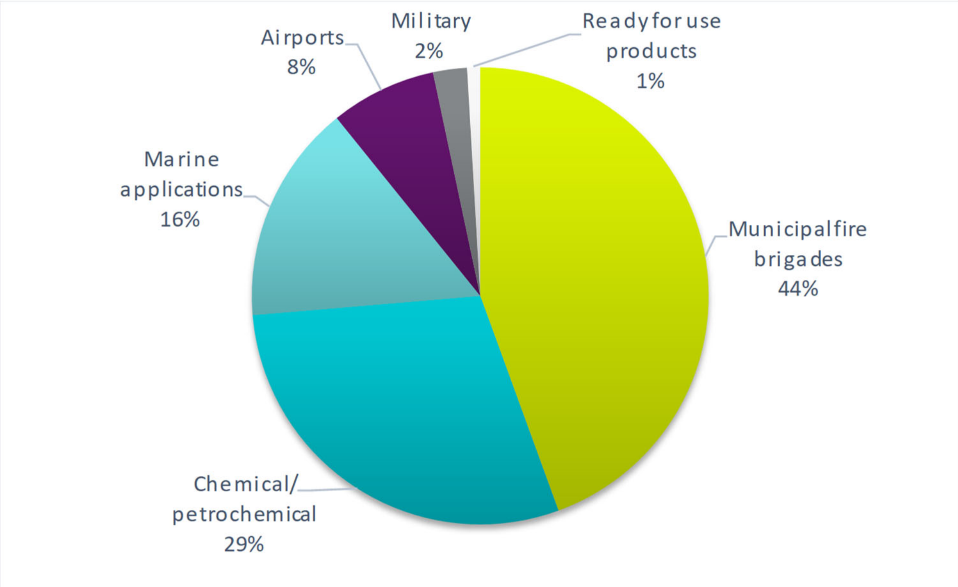
Sales of fire-fighting foams by user sector

Consultation with Eurofeu provided figures on the yearly consumption of fluorine-free firefighting foams in various sectors in Europe, based on a 3-year average (2016-2018), highlighting a total use of 6,553 tonnes per year. Of these 6,553 tonnes, 2,134 are utilised in fixed systems and 4,418 in mobile systems[39]. The split by sector is detailed in Figure 4.2 below. Notably, it varies considerably from that of PFAS-based foams, with a much larger share used by municipal fire brigades but a much smaller share in the chemical/petrochemical sectors.

[38] A respondent responsible for railway maintenance stated that PFAS-based foams are used in railways; the use of fire-fighting foams is particularly relevant for fire-protection in railway tunnels. The reason is that railways can carry various chemicals and other dangerous goods and, if they catch fire in tunnels, it is particularly critical and fires can be much more difficult to extinguish.

[39] The number of companies that provided a response on whether the foams are used in fixed or mobile systems is lower than those that provided a response for the sectoral overview, therefore in the original data the total tonnage of the former is lower than the latter. To fill this gap, the tonnages for both fixed and mobile systems have been inflated so that their total matches the total in the sectoral split. The original values are 1,259 tonnes for fixed systems and 2,605 tonnes for mobile systems (total 3,864 tonnes).

Figure 4.2 Yearly use of fluorine-free firefighting foams by sector.



Source: Data provided to the authors by Eurofeu.
Notes: The majority of the 'ready for use products' are fire extinguishers. However, not all foam fire extinguishers use ready-for-use foams.

Eurofeu estimate that the data they provided based on an internal survey covers roughly 70% of the EU market. It is therefore estimated that the total EU use of fluorine-free fire-fighting foams could be in the order of 9 million tonnes[40].

Other information on tonnages from the consultation

The following information on tonnages was provided in the consultation. Information on which chemical group of alternatives (based on the grouping established in the substance identification, see Section 3) is also listed.

- Additional fire-fighting foam manufacturers (not covered by Eurofeu's internal survey) stated that they manufacture/import a total of 1,250,000 litres and sell 380,000 litres of PFAS-free foams (based on hydrocarbon surfactants) per year in the EU. Assuming a density of approximately 1 kg/l, this would be equivalent to about 380 tonnes of foam that can be added to the Eurofeu total (but would already be included in the EU total extrapolated from Eurofeu data). Hover, given the exact sector split is not known, they have not been added to the sector breakdown;
- One respondent operating in fire protection for oil refineries/storage, chemicals, petrochemicals and municipalities provided figures for three types of fluorine-free foams (chemical groups of alternatives unknown) used for different purposes:
  - The first is used by the respondent for exercise and testing of fixed systems (i.e. not for fire-fighting), about 12-20 times per year at 300-10,000 kg per use. They purchase 15,000-30,000 kg of this foam per year;
  - The second is used by the respondent for testing of proportioning systems (i.e. not for fire-fighting), typically 4-6 times per year, with 1,000-6,000 kg used in each instance. They purchase 10,000 kg of this product per year; and

[40] Calculated as 13,669 tonnes divided by 70% and rounded to the closest million tonnes.

    - The third was due to start testing in autumn 2019, therefore they did not yet have any experience on real fires with this foam. It is expected that this product will be used about 50 times per year, with 1-400 kg used in each instance.
- One respondent operating in the field of industrial safety, particularly dedicated to technical support and training, provided figures for two different fluorine-free foams, both used for training purposes:
    - The first (a product shown to contain detergents according to the substance identification task) is used by the respondent for hydrocarbon fires in the oil and gas sector, with a typical frequency of 150 days per year. They purchase 4,000 kg of this product per year; and
    - The second (chemical group of alternatives unknown) is used by the respondent for alcohol fires, about 30 days a year. They purchase 1,000 kg of this foam per year.
- One respondent providing training in the safety sector gave figures for one type of fluorine-free foam (a product shown to contain detergents according to the substance identification task). This is used only for training purposes on fires of different sizes and in various sectors, such as airports, oil and gas and marine. They purchase 1,200 kg of this product a year and typically use it around 4 hours per week, depending on the training activity;
- One respondent active in the airport sector provided figures for one fluorine-free foam (a product shown to contain hydrocarbon surfactants and detergents according to the substance identification task), which is used for all aircraft applications and training activities. They purchase 3,600 litres of this foam a year. Approximately 300 litres are used each month, with a typical use of 15 minutes per month;
- Another respondent working in the airport sector stated that they purchase 5,000 litres per year of a fluorine-free foam (chemical group of alternatives unknown), which is used only for training and system testing; and
- Additional respondents have stated they use fluorine-free foams based on hydrocarbon surfactants and detergents in aviation, offshore oil installations and onshore terminals and refineries, without specifying quantities.

Respondents quoted prices for fluorine-free foams ranging from €0.7 to €10 per litre. For those fluorine-free fire-fighting foams for which data on tonnage and price is available, the weighted average price is around €3 per litre, but note that these products reflect only a small share of the total market, so this estimate is uncertain. Although the range is lower and the average is similar to prices of PFAS-based foams (see above), some respondents suggested that fluorine-free foams are around 50% more expensive than comparable foams containing fluorine. However, fluorine-free foams are still predicted to have a growing presence on the market, due to increasing regulations/controls on fire-fighting training and testing.

Conclusions

Based on information provided by Eurofeu and additional manufacturers, it has been estimated that at least some 7,000 tonnes, but probably around 9,000 tonnes of fluorine-free firefighting foams are sold in the EU annually.

A breakdown by chemical group of alternatives (based on the grouping established in the substance identification) is not available, but consultation responses suggest that the main alternatives used are based on hydrocarbon surfactants and detergents.

The split by sector of use varies considerably from that of PFAS-based foams, with a much larger share used by municipal fire brigades but a much smaller share in the chemical/petrochemical sectors.

Prices for fluorine-free foams range from €0.7 to €10 per litre, with the average estimated around €3 per litre (subject to significant uncertainty).

Functions provided in the foams and types of fires the foams are used for

The fluorine-free fire-fighting foams considered in this analysis are specifically those that can potentially be used as alternatives to the PFAS-based foams. As such, they are potentially used in the same applications. The consultation responses specifically indicated that fluorine-free alternatives are currently used for training, process fires, alcohol fires and fuel fires, as well as for testing proportioning systems and are applied both with fixed and mobile equipment. When it comes to the application of the products, no significant differences between fluorine-based and non-fluorine foams have been highlighted from a market perspective, but this is analysed in more detail in the analysis of alternatives (see Section 7).

The substance identification (Task 1) identified the following groups of substances that PFAS-free fire-fighting foams are based on: hydrocarbons, siloxanes, protein foams, detergents. All of these groups largely mimic the function of fluoro-surfactants in the PFAS-based fire-fighting foams, for instance hydrocarbon foams use hydrocarbon surfactants[41], siloxanes are also primarily used in fire-fighting foams to function as surfactants[42] and detergents are by definition surfactants.

4.5 Summary of results

The table below summarises some of the key results that have been discussed in more detail above.

Table 4.3 Summary of key preliminary market analysis results

	PFAS-based fire-fighting foams	Fluorine-free alternatives
Tonnage of foam used [1]	14,000-20,000 tonnes per year	7,000-9,000 tonnes per year
Tonnage by substance / Substances most commonly used	480-560 tonnes of fluoro-surfactants used annually in EU. Breakdown of tonnage for 8 substances available (see Table 4.1 and directly below the table), but for majority of tonnage the substances are not known.	No quantitative data. Main alternatives used are based on hydrocarbon surfactants and detergents. Specific products are discussed in Section 9(analysis of alternatives).
Breakdown of tonnage by use sector	Chemical/Petrochemical: 59% Municipal fire brigades: 13% Marine applications: 11% Airports: 9% Military: 6% Ready for use products: 1%	Chemical/Petrochemical: 29% Municipal fire brigades: 44% Marine applications: 16% Airports: 7% Military: 2% Ready for use products: 1%
Prices	Average (uncertain): €3 Reported range: €2 to €30 per litre	Average (uncertain): €3 Reported range: €0.7 to €10 per litre
Revenues [2]	Best estimate: €60 million Potential range: €28-600 million	Best estimate: €27 million Potential range: €5-90 million

[41] See for example: https://www.fomtec.com/fluorine-free/category38.html or https://www.chemguard.com/about-us/documents-library/documents/Martin2009ReebokEcoguardpresentation2010-10-11.pdf.
[42] See for example: https://www.nfpa.org/-/media/Files/News-and-Research/Resources/Research-Foundation/Symposia/2016-SUPDET/2016-Papers/SUPDET2016Hetzer.ashx?la=en.

	PFAS-based fire-fighting foams	Fluorine-free alternatives
Functions provided and types of fires used for	Surfactant to form a film over the burning surface. Particularly relevant for fire involving flammable liquids (Class B fires). Consultation suggests it is used both in training and true emergency responses.	Those fluorine-free foams considered alternatives to PFAS-based foams in principle provide the same (or a similar) function. Consultation suggests it is used both in training and true emergency responses, but in some cases in training only.
Trends	Rapid shift from PFAS towards fluorine-free foam in recent years, expected to continue.	

Notes: [1] The original data from Eurofeu covers approximately 70% of the market, therefore this has been inflated to reflect the whole market. The lower end of the range represents the original data, whilst the upper end represents the extrapolation to the whole market. [2] The best estimate is based on the upper end of the quantity range and a weighted average price of €3/litre. The potential range is based on the lower end of the quantity range multiplied with the lower end of the price range, and the upper end of the quantity range multiplied with the upper end of the price range. An average density of 1 kg/litre has been assumed.

5. Task 3. Assessment of the emissions and hazard of fluorine-free foams

5.1 Introduction

The focus of this task is to estimate the emissions of PFAS and of the constituents of the alternative fluorine-free fire-fighting foams to the environment, broken down by environmental compartment (atmospheric, aquatic, and terrestrial environments) and the possible uptake by humans via the consumption of food and water. Task 3 also covers the hazard (and risk, to the extent possible) to human health, the environmental and humans via the environment of the fluorine-free foams[43]. The development of emission estimates is expected to follow the relevant guidance provided by ECHA[44].

During the inception meeting it was clarified that the study should help to understand the emission pattern throughout the life cycle so that releases can be compared across foam products. For example, how much foam is used; how much of it is collected; how much is then incinerated; do the foams contaminate other environmental compartments and if so, how much ends up in each compartment?

Therefore, rather than using risk assessment models such as EUSES, a source-flow approach has been applied.

Due to the persistent nature of PFAS and non-threshold effects, releases of PFAS are of primary importance, and these are to be considered a proxy for exposure, as discussed at the inception meeting. The starting point for this task, therefore, has been to focus on releases and to compare those amongst PFAS-based foams and the alternatives. It was agreed at the inception meeting that, only if the alternatives are particularly hazardous for the environment should modelling be considered[45].

One further point to note is that the emission estimates that have been developed are intended to provide an illustrative assessment to help better understand the material flow and key emission compartments. The findings presented here are not a detailed risk assessment and are not presented within any geographical disaggregation based on identified sites in the European Union.

5.2 Approach

Development of the source-flow model

Based on guidance from ECHA, the UNECE inventory guidebook[46], and OECD Emission scenario document for AFFF a basic source-flow model has been developed to make use of the data from Task 1 and 2 (as a Microsoft Excel workbook). The development of this source-flow approach began with a consideration of what might be the key life-cycle stages and what kinds of emissions may occur at each life-cycle stage, which has incorporated the approach used within the PFOA restriction dossier under REACH.

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[43] The terms of reference also refer to those associated with any non-PFAS fluorinated alternatives, if they exist. However, as confirmed in this study, such alternatives have not been identified.

[44] See available guidance documents at: https://echa.europa.eu/guidance-documents/guidance-on-reach

[45] If it is decided that modelling of exposure is useful the type of modelling usually applied for exposure estimation within risk assessment of chemicals is based on fugacity (i.e. the propensity for a substance, based on its physicochemical properties - such as the octanol-water partition coefficient and Henry's law constant), to move from one environmental medium to another. In this case the partitioning between interstitial water and organic carbon within the soil matrix will be of high significance, when foams are used for land-based fires and runoff is not contained by a bund. Comparison with reliable measured data is a useful validation of the model method used.

[46] https://www.eea.europa.eu/themes/air/emep-eea-air-pollutant-emission-inventory-guidebook/emep

Based on this analysis the model development began with four basic life-cycle stages where it was possible for emissions to occur, or material to flow through into the next life cycle stage:

- Formulation of the fire-fighting foam concentrate. This includes consideration of the PFAS and fluorine-free substances used as surfactants within the foam concentrate. Note, that it was assumed that the life-cycle begins at this stage rather than the manufacture of the surfactants themselves. This distinction is made on the basis that the manufactured surfactants may have multiple applications, not limited to only fire-fighting foams. The full range of possible applications for a given PFAS or fluorine-free surfactant is outside the scope of the current study;
- Storage. Storage is considered a key life cycle stage with quantities of foam concentrate reaching expiry before active use[47]. During storage of foam concentrate it may be possible for leaks or spillages to occur, which directly contribute to environmental emissions. However, for usage sites (airports, refineries, terminals, industrial sites and military sites), appropriate risk management systems will generally be in place meaning that such leaks/spillages can be contained from direct release and will more likely act as an input to the waste/waste water system (e.g. sewers). Efficacy and management of materials put to sewer are further managed under waste;
- In-use. Active use of fire-fighting foams forms likely the most important life-cycle stage. The model developed defines two types of use. Firstly 'training' exercises, which are assumed to happen within contained conditions (i.e. bunding / capture systems are in place to capture and retain runoff)[48]; and secondly 'live' incidents which assumes no containment and full loss to the environment (following the approach adopted with the PFOA Annex XV dossier)[49]; and
- Waste. The waste cycle includes two key pathways. Firstly, incineration of any expired stocks of foam concentrate. Secondly waste water treatment works, processing of materials from leaks/spillage during storage, plus some runoff from training exercises.

Formulation of the fire-fighting concentrate

The model has been designed to allow calculation of both quantities of fire-fighting foams manufactured within the European Union, and quantities of finalised fire-fighting foam concentrate imported and used in the EU. Only quantities manufactured within the European Union are assumed to lead to emissions and exposure at the formulation stage.

The PFOA Annex XV dossier assumes default worst case emission rates of 2.5% w/w to air, 2% w/w to water (assumed to be waste water system rather than direct release) and 0.2% to soil as a direct release from spillages / deposition during manufacture. In the absence of better data, the same release rates have been applied to the non-fluorinated alternatives.

Storage

Following manufacture and sale, the fire-fighting foam concentrates will pass into the storage phase of the life-cycle. A proportion of the annual sales will also go directly into use (see in-use phase), with the remainder

[47] BiPRO, 2010, Study on waste related issues of newly listed POPs and candidate POPs – comments that the average lifespan of firefighting foams is 15 years.
[48] It is recognised based on the stakeholder engagement that the standard of containment for training run-off has in the past not been optimal. However, because of the concerns raised around substances such as PFOS, it can be expected that the standards in use currently are a significant improvement upon standards from the early 2000s.
[49] ECHA, 2018, 'Background document - to the Opinion on the Annex XV dossier proposing restrictions on Perfluorooctanoic acid (PFOA), PFOA salts and PFOA-related substances', ECHA/RAC/RES-O-0000006229-70-02/F and ECHA/SEAC/RES-O-0000006229-70-03/F

held in store, sometimes for several years. Data on leakage rates / spillages was not identified during the study, and therefore a value based on expert judgement of 1% of total stocks has been applied.

In-use phase

The "in-use" phase of the model was then further refined to incorporate different kinds of use and application and how these may affect the type of emission and usage rate (i.e. use at airports vs municipal fire brigades for example). This included data from Eurofeu (gathered as part of Task 2) on industry sector splits, and data from Brooke et al (2004)[50] which highlighted that most of the fire-fighting foam in the private sector is used for training (93% w/w). In the absence of better data, it was assumed that, for public fire brigades, use will predominantly be focused on live incidents with a smaller quantity used for training, assumed to be 93% on live incidents and 7% on training.

Data from BiPRO (2010)[51] and Buser et al (2009)[52] quote usage rates of between 15% and 20% annually[53] The source-flow model therefore assumes usage rates of 17.5% for the majority of sectors. However, for the public fire service sector a usage rate of 50% per annum has been used[54]. The justification for this modification is that based on a survey of UK fire authorities public fire services primarily use fire-fighting foams for live incidents a quicker turnaround of stockpiles may be expected. A usage rate of 50% assumes a high rate of use for quantities purchased annually, with stockpiling of 50% to safeguard against larger emergency events where greater quantities of foam may be needed.

Finally, for training exercises, a factor has been added for the efficacy of bunding / control measures designed to manage run-off of fire-fighting waters during the training exercise. Extremely limited data was available on these aspects and therefore best estimates have been made based on expert judgement. Efficacy of the bunding for terrestrial applications was extrapolated to estimate ranges from 90-97% (assuming captured waters are passed to sewer / on site waste water treatment)[55], while for marine applications it is assumed all run-off is permitted to be released directly to sea with no capture and control. For live incidents we have used the values quoted within the REACH Annex XV dossier for PFOA, which assumes a 100% release (which should be considered a worst-case scenario), split evenly between surface waters and soil. Table 5.1 provides further details of how quantities of fire-fighting foam has been manipulated.

[50] Brooke et al (2004), "Environmental risk evaluation report: Perfluorooctanesulphonate (PFOS), Report produced for the England and Wales Environment Agency.

[51] BiPRO (2010), "Study on waste related issues of newly listed POPs and candidate POPs", Commission report under framework ENV.G.4/FRA/2007/0066.

[52] Buser et al (2009), 'Substance flow analysis of PFOS and PFOA in Switzerland. Environmental Studies 0922. Federal Office for the Environment, Bern.

[53] BiPRO 2010 base their estimates on usage rates against a survey of UK fire authorities completed by RPA in 2004. This suggested that annually 15% of total stocks are used across all sectors (public and private). Usage rates by municipal fire and rescue services were higher at between 40% and 50%. Buser et al 2009 base their estimates on remaining stocks of PFOS within all sectors (public and private services) using 20% of all stocks annually. To maintain a steady flow of business it is assumed that both public and private brigades will replace stocks as use occurs, so replacement foam would be purchased annually.

[54] RPA, (2004), "Risk reduction strategy and analysis of advantages and drawbacks for PFOS", Report on behalf of Defra.

[55] Responses from the stakeholder engagement stated that 100% of training run-off is expected to be captured and retained, however, further statements from fire-fighters indicated that full capture is challenging and not always possible. The model therefore makes an assumption that minor losses will occur equivalent to 3% in the best cases, and at worst 10% for sectors with less well-defined sites of use and capture.

Table 5.1 Industry splits and usage rates based on data from Eurofeu and Brooke et al (2004)*

Sector	Percentage share of total	Annual usage rates (of total quantity sold annually)	Live incidents (as a percentage of total use)	Training (as a percentage of total use)	Efficacy of bunding/control measures for training
Military	6%	17.5%	7%	93%	90%
Civil Aviation	9%	17.5%	7%	93%	97%
Municipal Fire Services	13%	60%	93%	7%	90%
Chemical/petrochemical	59%	17.5%	7%	93%	97%
Marine Applications	12%	17.5%	7%	93%	0%
Ready to use applications	1%	17.5%	100%	0%	N/A

*For live incidents a 100% release is assumed split evenly between releases to surface water and soil. In the case of marine applications this is a 100% release to sea.

Waste phase

All material not lost directly to the environment during use will enter the waste phase through a variety of pathways (i.e. capture of run-off; spillages/leaks during storage entering on-site drains; unused foam concentrate which has expired), highlighting this phase's importance in the overall control and release to environment. The waste phase of the model aggregates the quantities of specific substances from different pathways to calculate total quantity per substance within the overall waste phase. This is then managed either by incineration (for end of life unused stocks) or waste water treatment works for retained runoff, losses to sewer from spillage/leakage during storage[56]. The model then applies two factors, firstly a distribution factor (as K_{oc}[57]) taken from REACH registration dossiers to understand how the substance partitions between liquid and sludge phases of the waste water process. Then secondly an efficacy factor is applied to reflect how successfully the waste water process destroys the substance, and how much remains unchanged as a direct release to environment.

Data on the efficacy of waste water treatment works against named substances was very limited for non-fluorinated alternatives. For the PFAS-based surfactants used in fire-fighting foam concentrates the efficacy is expected to be very low. The model assumes an efficacy of zero with all PFAS substances passing to environment unchanged. For the hydrocarbon-based alternatives, some are readily biodegradable, while others with more complex organic structures may be more resistant to degradation. For non-fluorinated alternatives the efficacy ranges from 99% for substances such as alcohols, and as low as 50% for aromatics.

The model assumes all waste sludges are then applied to farmland as a release to soil. Note, that while we recognise that this is a common waste management practice for sewage sludge, this is not the case across the EU (for example the application of sewage sludge to land in Denmark is banned). The model acts as a high-level assessment of which compartments are the most important for emissions and key variables affecting emissions. No geopolitical splits are applied to the data for importance of environmental compartments in different Member States.

[56] It is assumed that the sites in question will store these materials in secure areas with either bunding or on-site drainage. If there is a spillage/leak it is assumed that it will be contained and enter the waste systems.
[57] K_{oc} = Is a normalised partition coefficient used to calculate how much of a given substance will adsorb to organic matter. It is used as a measure for mobility of a given substance (primarily within terrestrial environments) but can be used as a measure of partitioning between liquid phases and organics within a wastewater treatment works.

In terms of the proportion of material sent to waste water treatment works and proportion sent for incineration, only limited information was available. It is assumed that all retained run-off water, and losses from spillage/leakage to drain on controlled sites are sent to either onsite WWTWs or municipal WWTWs dependent on the site. The use of incineration would be retained for unused expired fire-fighting foam concentrate, but on this matter, there is conflicting information. A number of references (RPA, 2004; Buser et al 2009; and BiPRO, 2010) suggest usage rates of around 15-20% of existing stocks per annum, with an AFFF shelf-life of up to 15 years, which would suggest all foam concentrate is used before expiration (on average). Discussions held at the 2018 POPs Review Committee (POPRC) meeting on exemptions for PFOA (its salts and related-compounds), included comments from a number of NGOs that significant quantities of expired foam concentrate was destroyed, particularly from private fire brigades, where live use was much less common.

The assumed usage rate of 15-20% per annum of existing stocks is an average across all sectors of use. This means that there will be installations with potentially far lower usage rates annually, increasing the potential for quantities to reach expiry before use. However, no data has been identified to quantify the amounts sent for incineration beyond commenting that waste water treatment is likely to be the dominant method for management of material in the waste cycle based on the outputs of the source-flow calculations. The model developed for the current study is a high-level assessment using the available references (including usage rates and shelf-life) meaning that the model assumes no material is sent for incineration.

Section 8.2 (subsection j. Emissions from disposal of legacy foams) provides some further insight to incineration of PFAS. This notes that, in general, PFAS emissions from incineration are not well studied. However, the chemistry of PFAS makes it resilient to thermal destruction. The US EPA (2019)[58] comments on studies (from 2004 and 2014) that showed for PFOA temperatures of 1,000 Celsius and residence time of 2 seconds were sufficient to destroy the PFOA. Kemi (2016)[59]. comments that more widely for PFAS compounds temperatures of at least 1,100 Celsius are needed, and that longer-chain PFAS species are more readily destroyed (potentially breaking down to shorter chain PFAS compounds), with the CF_4 species the most resilient. For CF_4 chemistry temperatures of 1,400 Celsius are required, with the breakdown products including carbon dioxide and hydrogen fluoride.

As a side note, the industrial emissions directive (2010/75/EU) requires waste incineration plants to operate at temperatures of at least 850 Celsius with residence time of at least two seconds. This would cover standard municipal waste incineration plants. For elevated temperatures >1,000-1,400 Celsius this is likely to require more specialised commercial hazardous waste incineration, noting that a more limited fleet of specialised high-temperature operators exist across Europe.

Summary of assumptions applied to the model

Table 5.2 provides a summary of all factors applied within the model that manipulates the flow of substances from formulation to waste cycle, including emissions at different life-cycle stages.

Table 5.2 Summary of factors applied to data

Life cycle stage	Description	Value	Reference
Formulation	Emissions during formulation of fire-fighting foam concentrates	2.5% w/w to air; 2% w/w to waste water; 0.2% to air	PFOA Annex XV dossier – assume same values for non-fluorinated alternatives.
Storage	Lifespan of concentrate	15 years	BiPRO (2010)

[58] US EPA, 2019, 'per and polyfluoroalkyl substances (PFAS): Incineration to manage PFAS waste streams', USEPA innovation report.
[59] https://www.kemi.se/global/rapporter/2016/report-11-16-strategy-for-reducing-the-use-of-higly-fluorinated-substances-pfas.pdf

Life cycle stage	Description	Value	Reference
Storage	Annual leak rate / spillage	1% w/w of total stocks	Assumed value based on expert judgement.
In-Use – Training	Industry sector splits	See Table 5.1	Eurofeu and Brooke et al (2004)
In-Use – Training	Usage rates annually	See Table 5.1	BiPRO (2010) and Posner (2019)
In-Use – Training	Efficacy of capture systems for run-off	See Table 5.1	Assumed value based on expert judgement.
In-Use – Live incidents	Emission to environment	Assumed to be 100%; 50% surface water, 50% soil. For Marine applications 100% sea.	PFOA Annex XV dossier.
Waste cycle	Efficacy of incineration	99%. Note for PFAS based foams could be lower, but in lieu of data assume 99% for all substances, and use of high temperature waste incineration	Assumed value based on expert judgement.
Waste cycle	Partitioning for liquid/sludge	Based on K_{oc} values per substance	REACH Registrations
Waste cycle	Efficacy of treatment	Varies. For PFAS based substances assumed efficacy is zero. For hydrocarbons assumed efficacy varies from 50% - 99% depending on complexity and physicochemical properties.	Feedback from workshop.
Waste cycle	Final disposal.	Assume treated effluent is direct release to surface water. Assume treated sludge is placed on farm land as direct release to soil.	Expert judgement.

Selection of products and substances for emission estimation

The selection process for named non-fluorinated substances was intended to identify those substances found in the products most commonly used, and where the hazards for human health and environment were of the greatest concern. To identify these substances a four-step process was followed as detailed below:

Step 1 – Collation of all substances

The outputs of Task 1 identified 168 non-fluorinated fire-fighting foam commercial products. In practice the surfactant action of the non-fluorinated products required the use of more than one substance, with most products therefore using a combination of named substances. Furthermore, the same substance is often found in multiple products across different manufacturers. However, the named substances identified could be broadly grouped into four categories (as identified in Task 1):

- Proteins;
- Siloxanes;
- Hydrocarbons; and
- Detergents.

Step 2 – Most common products

Based on the market analysis and stakeholder engagement from Task 2, the most commonly named products in use were given priority and screened in for the final selection. Based on analysis of the "screened in" set, the highest priority products (most commonly named five) were passed into the next phase. This included:

- Respondol ATF 3/6 – manufactured by Angus Fire;
- Moussol FF 3x6 – manufactured by Sthamer;
- Orchidex Bluefoam – manufactured by Orchidee;
- Re-healing foam RF11% - manufactured by Solberg; and
- Re-healing foam RF3x6 ATC – manufactured by Solberg.

Step 3 – Final selection of substances

Once the prioritised set of products was identified, the composition of products was identified (using safety data sheets) and hazard classification based on CLP. Using this approach those substances with hazard classifications relating to human or environmental toxicity were selected for use in the source-flow model.

Table 5.3 provides details of the specific substances where emission estimates have been developed. Note where ranges have been provided the upper limit has been used for the calculations as a conservative estimate.

Table 5.3 Final selection of substances (substances highlighted in blue selected) – see also footnotes at end of table.

Product	Substance	Category	CAS number	Concentration in product % w/w	Hazard classification	Degradation and fate*
Respondol ATF 3/6	1-dodecanol	Detergent	112-53-8	0.1 to 1	Eye Irritant. 2 Aquatic Acute 1 Aquatic Chronic 2	Short lived in air (<24 hours) and soil, likely to volatise from water to air.
Respondol ATF 3/6	1-tetradecanol	Detergent	112-72-1	0.1 to 1	Eye Irritant. 2 Aquatic Chronic 1	Short lived in air (<24 hours) and soil (5.5 days), likely to volatise to air from water and wet soil but remains in dry soil until degraded.
Respondol ATF 3/6	1-butoxy-2-propanol	Hydrocarbon	131-66-8	4 to 10	Skin Irritant. 2 Eye Irritant. 2	(E) Likely to be short lived in air and soil, as an alcohol it should denature in water and would be expected to volatise.
Respondol ATF 3/6	Sulfuric acid, mono-C8-10 (even numbered)-alkyl esters, sodium salts	Detergent	5338-42-7	1 to 4	Skin Irritant. 2 Eye Damage. 1	ECHA database of registered substances under REACH (ECHA DB): Water: 92% degraded after 30 days.
Respondol ATF 3/6	1,2-propanediol	Hydrocarbon	57-55-6	4 to 10	Not classified	When released to air will exist solely in the vapour phase, half-life in air is short (32 hours), Highly mobile in soil, but less likely to volatise, breakdown in soil processes important (<60 days). In water does not bind to suspended solids but remains in aqueous phase. Testing at WWTWs suggests readily breaks down in water.
Respondol ATF 3/6	Sodium laureth sulphate	Detergent	8891-38-3	to 4	kin Irritant. 2 Eye Damage. 1 Aquatic Chronic 3	ECHA DB: notes that based on distribution modelling that the primary receiving environment is water. Based on REACH dossiers suggests it is readily biodegradable in water.
Moussol FF 3x6	ALKYLAMIDOBETAINE (SAME EC BUT OTHER CAS)	Detergent D	61789-40-0	<5	Skin Irritant. 2 Skin Sensitiser. 1 Eye Irritant. 2 Aquatic Chronic 3	ECHA BD: Half-life in water (at 25C) is 15 days; in sediment at (at 25C) is 4.5 months. Half-life in soil (at 25C) is 30 days.
Moussol FF 3x6	1,2-ETHANDIOL	Hydrocarbon	107-21-1	<10	Acute Toxicity. 4 * STOT RE 2	When released to air will exist solely in vapour phase, half-life in air is short (48 hours), Highly mobile in soil, but less likely to volatise, breakdown in soil processes important (half-life is <12 days). In water does not bind to suspended solids but remains in aqueous phase. Half-life in water was <14 days at 8 Celsius.

Product	Substance	Category	CAS number	Concentration in product % w/w	Hazard classification	Degradation and fate*
Moussol FF 3x6	2-(2-BUTOXYETHOXY)ETHANOL	Hydrocarbon	112-34-5	<10	Eye Irritant. 2	Half-life in air is short (<5 hours). Within soils will be highly mobile but readily biodegradable. In water will not bind to suspended solids (remains in aqueous phase). Readily biodegradable in water.
Moussol FF 3x6	ALKYLAMIDOBETAINE	Detergent	147170-44-3	<5	Acute Toxicity. 4 Skin Irritant. 2 Eye Damage. 1 Acute Toxicity. 4 STOT SE 3 (respiratory tra...) (Inhalation) Aquatic Chronic 3	ECHA BD: Half-life in water (at 25C) is 15 days; in sediment at (at 25C) is 4.5 months. Half-life in soil (at 25C) is 30 days.
Moussol FF 3x6	TRIETHANOLAMMONIUM-LAURYLSULFATE	Detergent	85665-45-8	<10	Acute Toxicity. 4 Skin Irritant. 2 Eye Damage. 1 Acute Toxicity. 4 STOT SE 3 Aquatic Chronic 3	(E) Would expect this compound to be readily biodegradable in water. Half-life likely to be days-weeks (<30 days)
Orchidex BlueFoam 3x4	107-21-1 Ethandiol (vgl. Glykol) 5 - < 10 %	Hydrocarbon	107-21-1	5 - < 10 %	Acute Toxicity. 4 * STOT RE 2	When released to air exists solely in vapour phase for air, half-life in air is short (48 hours), Highly mobile in soil, but less likely to volatise, breakdown in soil processes important (half-life is <12 days). In water does not bind to suspended solids but remains in aqueous phase. Half-life in water was <14 days at 8 Celsius.
Orchidex BlueFoam 3x6	9 D-Glucopyranose oligomeric C10-16-alkyl glycosides	Detergent	110615-47-9	1 - < 5 %	Skin Irritant. 2 Eye Damage. 1	ECHA DB: Half-life in air <5 hours; fully biodegrades in water.
Orchidex BlueFoam 3x3	2-(2-Butoxyethoxy)ethanol	Hydrocarbon	112-34-5	15 - < 20 %	Eye Irritant. 2	Half-life in air is short (<5 hours). Within soils will be highly mobile but readily biodegradable. In water will not bind to suspended solids (remains in aqueous phase). Readily biodegradable in water.
Orchidex BlueFoam 3x5	Ammonium laureth sulfate	Detergent	32612-48-9	1 - < 5 %	Skin Irritant. 2 Eye Irritant. 2	(E) Only limited data available, review of multiple SDS all comment that this substance is readily biodegradable in water. Half-life likely to be days-weeks (<30 days)
Orchidex BlueFoam 3x7	Ammonium alkyl C10-C16 sulphate	Detergent	68081-96-9	1 - < 5 %	Skin Irritant. 2 Eye Dam. 1	(E) Would expect this compound to be readily biodegradable in water. Half-life likely to be days-weeks (<30 days)
Re-Healing Foam RF1 1%	sucrose (-)	Hydrocarbon	57-50-1	>1%	Not classified	(E) Readily biodegradable.
Re-Healing Foam RF1 1%	1-propanaminium, 3-amino-N-	Detergent	61789-40-0	≤10%	Skin Irritant. 2 Skin Sensitiser. 1	ECHA BD: Half-life in water (at 25C) is 15 days; in sediment at (at 25C) is 4.5 months. Half-life in soil (at 25C) is 30 days.

Product	Substance	Category	CAS number	Concentration in product % w/w	Hazard classification	Degradation and fate*
	(carboxymethyl)-N,N-dimethyl-, N-coco acyl derivs., hydroxides, inner salts (-)				Eye Irritant. 2 Aquatic Chronic 3	
Re-Healing Foam RF1 1%	2-(2-butoxyethoxy)ethanol (01-2119475104-44)	Hydrocarbon	112-34-5	≤20%	Eye Irritant. 2	Half-life in air is short (<5 hours). Within soils will be highly mobile but readily biodegradable. In water will not bind to suspended solids (remains in aqueous phase). Readily biodegradable in water.
Re-Healing Foam RF1 1%	sodium octyl sulphate (-)	Detergent	142-31-4	≤10%	Skin Irritant. 2 Eye Damage. 1	ECHA DB: Half-life in air 42 hours. Expected to fully biodegrade in water.
Re-Healing Foam RF1 1%	sodium decyl sulphate (-)	Detergent	142-87-0	<3%	Skin Irritant. 2 Eye Damage. 1 Aquatic Chronic 3	ECHA DB: Half-life in air 32 hours. Expected to fully biodegrade in water (92% after 30 days).
Re-Healing Foam RF1 1%	1-propanaminium, N-(3-aminopropyl)-2-hydroxy-N,N-dimethyl-3-sulfo-, N-coco acyl derivs., hydroxides, inner salts (-)	Detergent	68139-30-0	≤10%	Eye Irritant. 2	ECHA DB: Will biodegrade in water, 71% degraded after 28 days at 20 Celsius.
Re-Healing Foam RF1 1%	amides, coco, N-[3-(dimethylamino)propyl] (-)	Detergent	68140-01-2	<0.2%	Skin Irritant. 2 Eye Damage. 1 Aquatic Chronic 1	(E) Would expect this compound to be readily biodegradable in water. Half-life likely to be days-weeks (<30 days)
Re-Healing Foam RF1 1%	amides, coco, N-[3-(dimethylamino)propyl], N- oxides (-)sucrose (-)	Detergent	68155-09-9	≤1%	Acute Toxicity. 4 Skin Irritant. 2 Eye Damage. 1 STOT RE 2	ECHA DB: Sewage sludge test showed 93% degradation after 28 days.
Re-Healing Foam RF1 1%	D-glucopyranose, oligomers, decyl octyl glycosides (-)	Detergent	68515-73-1	<3%	Eye Damage. 1	ECHA DB: half-life in air <5hours; In soil and water fully biodegrades based on OECD test protocols.
Re-Healing Foam RF1 1%	sulfuric acid, mono-C12-14-alkyl esters, compds. with triethanolamine (-)	Detergent	90583-18-9	≤10%	Acute Toxicity. 4 Skin Irritant. 2 Eye Damage. 1 Aquatic Chronic 3	(E) Would expect this compound to be readily biodegradable in water. Half-life likely to be days-weeks (<30 days)
Re-Healing Foam RF1 1%	alpha-sulfo-omega-hydroxy-poly(oxy-1,2-ethanediyl), C9-11	Detergent	96130-61-9	<3%	Pre-Registration process	(E) Would expect this compound to be readily biodegradable in water. Half-life likely to be days-weeks (<30 days)

Product	Substance	Category	CAS number	Concentration in product % w/w	Hazard classification	Degradation and fate*
	alkyl ethers, sodium salts (-)					
Re-Healing Foam RF3x6 ATC	sucrose (-)	Hydrocarbon	57-50-1	>1%	Not classified	(E) Readily biodegrades
Re-Healing Foam RF3x6 ATC	2-(2-butoxyethoxy)ethanol	Hydrocarbon	112-34-5	≤20%	Eye Irritant. 2	Half-life in air is short (<5 hours). Within soils will be highly mobile but readily biodegradable. In water will not bind to suspended solids (remains in aqueous phase). Readily biodegradable in water.
Re-Healing Foam RF3x6 ATC	Starch	Hydrocarbon	9005-25-8	>1%	Not classified	(E) Biodegradable
Re-Healing Foam RF3x6 ATC	Cocamidopropyl hydroxysultaine	Detergent	68139-30-0	<2.5%	Eye Irritant. 2	ECHA DB: Will biodegrade in water, 71% degraded after 28 days at 20 Celsius.

* All degradation and fate data is based on Pubchem (https://pubchem.ncbi.nlm.nih.gov/), the ECHA database of REACH registered substances (ECHA DB) (https://echa.europa.eu/information-on-chemicals/registered-substances), or in cases where no information was found had been based upon expert judgement (E)

Step 4 selection of PFAS substances

Additionally, based on the outputs of the Task 2 market research and stakeholder engagement, the highest tonnage PFAS based substances were also selected for modelling in the source-flow model. This included the following two substances:

Table 5.4 PFAS based substances for selection

Fluoro-compound	CAS number	Tonnes per year	Share of the total market
1-Propanaminium,N-(carboxymethyl)-N,N-dimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulfonyl]amino]-,inner salt	34455-29-3	21.1	6%
1-Propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-N-[[(gamma-omega-perfluoro-C6-C16-alkyl)thio]acetyl] derives., inner salts	80475-32-7	17.2	5%

Extrapolation of activity data

The outputs from Task 2 provided valuable information on which non-fluorinated products are most commonly in use. However, data on specific quantities per product was largely incomplete. Therefore, a different approach was needed to help develop emission estimates. Data provided by Eurofeu (which represents 60-70% of foam producers) provided data for total quantities of PFAS-based and non-fluorinated based products as an aggregated total. This has been further extrapolated to derive estimated total EU sales of 20,000 tonnes of PFAS-based concentrate annually, and 9,000 tonnes of non-fluorinated alternatives annually (see Section 4).

The stakeholder engagement also identified 12 manufacturers of non-fluorinated alternatives. The aggregated 9,000 tonnes has therefore been allocated equally across all 12 manufacturers, and further disaggregated based on number of products per manufacturer.

This approach allows a fair assessment of the source-flow of material and order of magnitude estimates. The key limitation however is that some products will likely be used more widely than others. Suitable market data to provide specific quantities per product was unavailable.

5.3 Results and analysis

Key messages from emission source-flow model

The source-flow model has been used to produce emission estimates for 10 unique non-fluorinated substances (noting that two substances appear in multiple products, and further that alkylamidobetaine is listed with two different CAS numbers suggesting minor variation of the specific chemistry); as well as two PFAS-based substances.

The non-fluorinated alternatives include a combination of hydrocarbons and detergents as defined by the selection methodology. Tables 5.5 and 5.6 provide summary overviews (as percentage ratios) of the key emission compartments and life-cycle stages for emissions.

The initial overview of Table 5.5 highlights that fresh surface water and soil are the key receiving environmental compartments. Furthermore, Table 5.6 highlights that, for non-fluorinated substances, live incidents are the major point of release, while for PFAS the waste phase is the key life-cycle stage for emissions, primarily from losses associated with releases at WWTPs. The major reason for this difference is that, while non-fluorinated foams are readily expected to degrade within WWTPs (thus lowering the importance of the waste cycle), PFAS based foams are expected to undergo little or no degradation within WWTPs.

Table 5.5 Overview of ratios for emissions by different environmental compartment for all life-cycle stages combined.

Substance group	Air	Fresh surface water*	Marine waters	Soil
Non-fluorinated alternatives (range)	9 – 18%	33 -37%	10 – 15%	30 – 45%
Non-fluorinated alternatives (mean average)	14%	35%	13%	38%
1-Propanaminium,N-(carboxymethyl)-N,N-dimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulfonyl]amino]-,inner salt	9%	51%	8%	32%
1-Propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-N-[[(gamma-omega-perfluoro-C6-C16-alkyl)thio]acetyl] derives., inner salts	9%	30%	8%	53%

*includes releases from WWTPs after treatment.

Table 5.6 Overview or ratios for emissions by different life-cycle stages

Substance Group	Formulation	Storage and Training	Live	Waste
Non-fluorinated alternatives (range)	9 – 18%	12 – 18%	40 – 62%	1% - 35%
Non-fluorinated alternatives (mean average)	14%	15%	52%	19%
PFAS based substances (mean average)	9%	9%	30%	52%

Further examination of the data helps elaborate on the summary findings within Tables 5.5 and 5.6, with the following key points to help add context to the overview tables:

Management of runoff during training

The data from Brooke et al (2004) highlights that, aside from municipal fire brigades, the major use of fire-fighting foams is for training purposes. Feedback from the stakeholder consultation indicated that at least in some Member States and applications there will be local or national-level regulations in place governing containment and prevention of release of fire-fighting foam or firewater runoff to the environment, although it is not clear whether this is comprehensive. One possible exception is training for marine applications, where the more limited options likely means full loss of all firewater runoff to the marine environment.

The treatment scenarios developed in Task 4 on remediation costs (see Section 6.3) suggest that for large infrastructure installations (e.g. airports, petrochemical facilities, and fire-fighter training complexes) the site should be engineered to allow for a 100% capture of materials used in the training activity. Furthermore, for live emergencies at such sites where larger volumes may be used and are expected to be handled, capture of firefighting water should be done as soon as practicable and safe. However, also note that, for live incidents, the releases of firefighting foams are very situation-specific and site-specific, and , in reality, it may not be possible to retain all runoff from fire-fighting.

The specific kind of engineered options (hard surfaces, bunded areas, on-site drainage systems, etc.) will vary from site to site and the specific kind of operation being undertaken. As a further example of the practical application of how a given site may be managed, the UNECE good practice guidelines provide some further insight[60]:

"*There are several possible types of systems for the retention of contaminated firefighting water. The systems can be installed permanently (i.e. pre-installed water barriers or permanent retention basins, if necessary with pumping installations) or be provided as mobile facilities (i.e. fire-fighting water barriers, hoods and sealing pads, mobile storage tanks).*"

Firewater run-off can then be pumped into tanks and transported e.g. by trucks to treatment facilities. There are several short case studies of fire incidents with a description of retention and disposal of fire-water in Annex 1 of the UNECE good practice guidelines.

One further consideration is the management of fire-fighting foam or firewater runoff at either on-site waste water treatment works or municipal waste water treatment plants. Again, this is likely to vary from site to site and is determined in part by the frequency of training and quantities of material that need to be managed. On-site treatment plants would incur a significant cost in the construction and operational phases, as well as requiring a minimum level of throughput to make operations practical. In some cases (e.g. petrochemical works) it is possible that sites already have on-site WWTPs for other purposes and are able to manage firewater runoff as and when needed. In other cases where training is less frequent (e.g. only quarterly / twice a year) use of municipal waste water treatment plants under environmental permitting is more likely.

However, also note that where firewater runoff enters drains and is sent to municipal waste water treatment plants, the environmental permits may require some pre-treatment steps. For example, these could include the use of sediment traps to remove solids, an oil/water separator and possibly a granular activated carbon filter before discharge.

As a conclusion a distinction needs to be drawn between uses for training purposes and uses for live incidents, noting the potential for greater control over runoff from training compared to live incidents. A review of the evidence suggests that at national level there are regulations in place in several countries over the design and management of fire-fighting runoff for training, and best practice guidelines for live incidents. However, further data on how comprehensive the coverage of these measures is across the whole EU and their practical implementation has been more difficult to obtain, and, based the evidence analysed, it is not possible to conclude that substantial quantities of runoff could not be released to the environment across Europe, particularly from live incidents..

Processing of substances in waste water

Once within the waste water process two key factors determine how the substances identified are managed. Firstly partitioning (as K_{oc}) and secondly the efficacy of the works to successfully destroy the chemical before release. The Log K_{oc} values have been used a measure to help understand partitioning. In practice, the lower the K_{oc} Value the more 'water-loving' the substance, and the less likely it is to partition into the sludge phase. Table 5.7 provides log K_{oc} values for a range of substances to provide an indicative guide.

60 https://www.unece.org/fileadmin/DAM/env/documents/2017/TEIA/JEG_MTGS/UNECE_Safety_Guidelines_and_Good_Practices_for_Fire-water_Retention_14_Nov_2017_clean.pdf

Table 5.7 log K_{oc} values for a set of solvents, POPs and PFAS based substances as indicative guide to partitioning against K_{oc} values.

Substance	Substance type	Log Koc (l/kg)	Partitioning
Acetone	Solvent	0.24	Hydrophilic
Butanol	Solvent	0.84	Hydrophilic
Perfluorobutane sulfonic acid (PFBS)	PFAS	1.0	Hydrophilic
Perfluorooctanoic acid (PFOA)	PFAS / POP	1.3 – 2.4	Hydrophilic
Perfluorohexane sulfonic acid (PFHxS)	PFAS / candidate POP	1.8	Hydrophilic
Perfluorooctanesulfonic acid (PFOS)	PFAS/POP	2.5 - 3.1	Mixed
Endosulfan	Pesticide / POP	3.3	Mixed
Endrin	Pesticide / POP	4.09	Hydrophobic
Methoxychlor	Pesticide / Candidate POP	4.9	Hydrophobic
Polychlorinated biphenyls (PCBs)	POP	5.5	Hydrophobic
Poly aromatic Hydrocarbons (PAHs)	POP	6.2	Hydrophobic

Table 5.8 log K_{oc} values for non-fluorinated substances included within Task 3.

Substance	CAS number	Log K_{oc} (l/kg)	Partitioning
1,2-ETHANDIOL	107-21-1	0.0	Hydrophilic
Triethanol Ammonium-Laurylsulfate	85665-45-8	1.88	Hydrophilic
sodium decyl sulphate (-)	142-87-0	2.09	Mixed
Sodium laureth sulphate	68891-38-3	2.20	Mixed
Alkylamidobetaine	147170-44-3	2.81	Mixed
sulfuric acid, mono-C12-14-alkyl esters, compds. with triethanolamine (-)	90583-18-9	3.19	Hydrophobic
1-dodecanol	112-53-8	3.30	Hydrophobic
amides, coco, N-[3-(dimethylamino)propyl] (-)	68140-01-2	3.82	Hydrophobic
amides, coco, N-[3-(dimethylamino)propyl], N-oxides (-)sucrose (-)	68155-09-9	3.82	Hydrophobic
1-tetradecanol	112-72-1	4.53	Hydrophobic

Table 5.8 provides the log K_{oc} values for non-fluorinated substances which range from 1.8 to 4.5, with the exception of 1,2 ethanediol which has a K_{oc} value of zero. This means that while these substances are soluble, for many of them there is a greater tendency to partition to the sludge phase. The log K_{oc} values for the two PFAS species are 1.5 and 3.8, which means the partitioning is more mixed, with the CAS 34455-29-3 species having much greater solubility and mobility. This places greater onus on the releases from WWTPs, noting that the efficacy of WWTPs for PFAS based substances is expected to be poor.

The other major factor is the efficacy of the works itself to irreversibly destroy specific substances. For the hydrocarbon-based alternatives, waste water treatment works could be expected to have a high level of efficacy, particularly against substances like 1,2 ethanediol which will readily disassociate. For detergent-based alternatives the efficacy may be less than for hydrocarbons, although overall efficacy is expected to be high (≥70%). By contrast waste water treatment efficacy against PFAS substances is expected to be poor with close to zero effectiveness. This makes partitioning particularly important for evaluating final emission of PFAS substances.

Summary conclusions

The overviews presented within Table 5.5 and 5.6 illustrate that significant use occurs for training purposes, with an assumption applied that runoff is largely retained and treated within waste water treatment works (although also noting that feedback from the study workshop and literature review highlights efficacy of WWTPs for PFAS substances is poor). For the non-fluorinated alternatives, the effectiveness of WWTPs is relatively good, minimising the emission which is split between surface water and soil. The effectiveness of the WWTPs to irreversibly destroy the named non-fluorinated substances, increases the importance of live incidents – where there is a direct release without treatment.

For the PFAS-based substances there is a similar process with the majority of retained fire-water run-off from training sent for treatment at WWTPs. However, the efficacy is expected to be poor, with WWTPs ineffective at treating PFAS, meaning direct release to surface water / soil depending on the partition coefficient. Waste is thus the most important life-cycle stage for the PFAS substances (shown in Table 5.6).

A further consideration within the results is the magnitude of emissions to different environmental compartments. Review of the data highlights a further two key points.

Firstly, the PFAS-based surfactants are effective at low concentrations within the fire-fighting concentrate (≤3% w/w based on data from the stakeholder engagement), while the hydrocarbon/detergent alternatives are potentially less effective, meaning greater concentrations are needed within the concentrate product (aggregate of all substances within a given product equates to 10-20% w/w). Secondly, for the non-fluorinated alternatives a combination of substances is needed together to be effective.

Based on the market analysis and stakeholder engagement, a small set of substances are used across multiple different manufacturers. This means that while the non-fluorinated fire-fighting foams make up approximately one third of the market, the volumes of alternative surfactants can be greater than their PFAS counterparts because of the greater concentration needed. By way of example:

- Taking uncertainty into account the emissions of alkylamidobetaine (CAS 61789-40-0) are estimated as 9.5 tonnes to water and 8 tonnes to soil annually for the European Union. This is based on an assumed annual sale of 86 tonnes (within different products); and
- As means of comparison, the PFAS surfactant 1-Propanaminium,N-(carboxymethyl)-N,N-dimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulfonyl]amino]-,inner salt (CAS 34455-29-3) has annual sales of 21.5 tonnes (within different products) and estimated emissions to water of 3.3 tonnes and to soil of 1.8 tonnes annually across the EU.

This reflects potentially higher emissions of the non-fluorinated alternatives, primarily due to greater concentrations within the product itself. However, it is important to recognise that emission alone is not an indicator of impact, and the degradation rates, potential for bioaccumulation, and harmful effects also need to be considered. The next sub-section provides a consideration of the hazards for non-fluorinated alternatives, before the final sub-section in this chapter combines the emission estimates with hazard data to consider potential risks from exposure via uptake / man-via-the environment pathways.

Review of hazards

In this sub chapter the hazards of the identified fluorine-free alternative substances have been assessed based on their PNEC (Predicted No Effect Concentration). As highlighted in ECHA´s guidance document on information requirements and chemical safety assessment (Chapter R.10: Characterisation of dose [concentration]-response for environment)[61], the PNEC represents "the concentration of the substance below which adverse effects in the environmental sphere of concern are not expected to occur".

Mostly, PNEC values are derived from acute and chronic toxicity single-species or multi-species data. To extrapolate from this data, an empirical assessment factor is necessary to make assumptions for the entire ecosystem. In combination with predicted environmental concentration (PEC) values PNECs are used to calculate a risk characterisation ratio. For this the PEC is divided by the PNEC, thus if the PNEC exceeds the PEC, it can be concluded that there is no environmental risk based on the concentration of the observed substance. However, in this project, the sole consideration of a PNEC value is not advisable, based on the uniqueness of PFAS substances. In an ecotoxicological assessment, this uniqueness is for example expressed by the fact that they are not biodegradable. ECHA's guidance document highlights that the "degradation of organic substances in the environment influences exposure and, hence, it is a key parameter for estimating the risk of long-term adverse effects on biota"[62]. Thus, in the following not only PNECs but also data on biodegradation and bioaccumulation is considered.

It should be noted that the following considerations are not meant as a full risk assessment; they are meant rather as an indicative comparison of the identified substances among each other and against the fluorinated substances.

Based on their REACH registration dossiers it was possible to identify most of the PNECs, biodegradation and bioaccumulation data of the fluorine-free alternative substances and the selected fluorinated substances. In the following table an overview of the substances, their respective products, CAS numbers, PNECs, bioconcentration factors (BCFs), and biodegradation assessments are given. Due to the focus of this project the PNECs for freshwater and soil were considered.

Table 5.9 Overview on substances used in fluorine-free fire-fighting foams and one substance used in a fluorinated foam. Shown are the product, CAS/EC, PNECs, and the used reference. The respective lowest PNECs are highlighted in bold.

Substance	Product	CAS	PNEC aqua (freshwater) mg/L	PNEC soil (mg/kg soil dw)	Bio-degradation (… biodegradable in water)	Bio-accumulation (BCF)	Reference
1-dodecanol	Respondol ATF 3/6	112-53-8	**0.001**	0.132	Readily	750	ECHA RD
1-tetradecanol	Respondol ATF 3/6	112-72-1	0.0063	0.428	Readily	**1000***	ECHA RD
Sodium laureth sulphate	Respondol ATF 3/6	68891-38-3	0.24	0.0917	Readily	waived	ECHA RD

[61] https://echa.europa.eu/documents/10162/13632/information_requirements_r10_en.pdf
[62] https://echa.europa.eu/documents/10162/13632/information_requirements_r7b_en.pdf

Substance	Product	CAS	PNEC aqua (freshwater) mg/L	PNEC soil (mg/kg soil dw)	Bio-degradation (... biodegradable in water)	Bio-accumulation (BCF)	Reference
Alkylamidobetaine	Moussol FF 3x6 Re-Healing Foam RF1 1%	61789-40-0	0.0032	0.0419	Readily	71*	ECHA RD
1,2-ethandiol	Moussol FF 3x6 Orchidex BlueFoam 3x4	107-21-1	10	1.53	Readily	waived	ECHA RD
Triethanolammonium-laurylsulfate	Moussol FF 3x6	85665-45-8	0.017	0.042	Readily	waived	ECHA RD
sodium decyl sulphate (-)	Re-Healing Foam RF1 1%	142-87-0	0.095	0.2445	Readily	waived	ECHA RD
amides, coco, N-[3-(dimethylamino)propyl] (-)	Re-Healing Foam RF1 1%	68140-01-2	No data				
amides, coco, N-[3-(dimethylamino)propyl], N- oxides (-)sucrose (-)	Re-Healing Foam RF1 1%	68155-09-9	0.0059	3.68	Readily	No data	ECHA RD
sulfuric acid, mono-C12-14-alkyl esters, compds. with triethanolamine (-)	Re-Healing Foam RF1 1%	90583-18-9	0.012	0.083	Readily	No data	ECHA RD
1-Propanaminium,N-(carboxymethyl)-N,N-dimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8-tridecafluorooctyl)sulfonyl]amino]-,inner salt	AFFF	34455-29-3	0.0326	**0.00133**	**Not readily**	450	ECHA RD
1-Propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-N-[[(gamma-omega-perfluoro-C6-C16-alkyl)thio]acetyl] derives., inner salts	AFFF	80475-32-7	0.009	1.17	**Not readily**	No data	ECHA RD

Explanatory note: Waived means, that the test was not required due to the results of other tests.
*An asterisk means, that this value was extrapolated based on calculations.

It is observable that the two fluorinated substances (CAS 34455-29-3 and 80475-32-7) are the only substances that are "not readily biodegradable in water" (data on biodegradation in soil is not available in the registration dossier)[63]. In addition, the substance with CAS 34455-29-3 also has the lowest PNEC for soil, meaning that, at concentrations higher than 1,33 µg/kg (ppb) a risk cannot be excluded. The combination of this value and with its relatively low PNEC for freshwater (0.0326 mg/l), shows, that this substance exhibits

[63] https://echa.europa.eu/de/registration-dossier/-/registered-dossier/17549/1

more hazard to the environment than any of the non-fluorinated substances. This finding is also supported by the fact that the treatment at WWTPs is ineffective (as shown in the previous subchapter). In terms of partitioning the fluorinated substance CAS 34455-29-3 has a log k_{oc} of 1.5, suggesting strong partitioning to treated effluent within WWTPs and release to surface water. Use during live incidents is assumed to be released equally to surface water and soil. This may suggest that the bigger impact for soils would come from live incidents.

However, some of the alternatives have both relatively low PNECs and relatively high biodegradation and/or bioaccumulation data. This is true for two alcohols (1-dodecanol and 1-tetradecanol). However, in comparison to the two fluorinated substances listed in Table 5.8, both of the non-fluorinated substances are readily biodegradable due to the rapid metabolism of long-chain fatty alcohols in fish, mammals and microorganisms (based on information taken from their registration dossiers). That means that, even if the substance is emitted to the environment in the context of a release from WWTPs or live incidents, it will be biodegraded rapidly. Furthermore, as highlighted in the previous section, based on these properties it could be expected that waste water treatment plants would have a high level of efficacy for the destruction of these substances.

Taken together, this review of hazards based on PNECs and data on biodegradation and bioaccumulation shows, that the two fluorinated substances should be considered of higher priority compared to the non-fluorinated substances when it comes to hazards and potential risks to the environment. This is due to the PFAS being both non-biodegradable and having relatively low PNECs for water and soil. Some of the alternative substances exhibit low PNECs, however, this needs to be considered in the context of their ready biodegradation. Further discussion on the hazards of the shortlisted alternatives can be found in Section7.5.

Further considerations for exposure via uptake from food

This final sub-section considers both the outputs of the emission model and the hazard assessment to identify further thoughts on the potential human exposure via uptake from food. This section is intended to provide first thoughts as a high-level review. Further work would be needed to assess the risks associated with specific sites or food production pathways, and that is beyond the scope of the current study.

The output of the emission model highlighted that, because the major use of fire-fighting foams is dominated by training, the efficacy of bunding/control measures is critical in preventing direct release to the environment. Secondly, the capacity of waste water treatment plants to successfully remove and/or destroy substances and prevent emission to environment is key to limiting their release to the wider environment.

The review of hazards highlighted that the fluorinated compounds have very low biodegradability and, in at least one case, very low PNEC values for soil. Furthermore, based on feedback from the workshop, the efficacy of waste water treatment plants against fluorinated compounds is typically poor. This suggests that the first major conclusion that can be drawn is that the PFAS-based compounds represent a greater risk to uptake and exposure than the non-fluorinated alternatives.

Further review of the non-fluorinated alternatives highlighted a number of compounds (see Table 5.8) that also have very low PNEC values for water and soil (albeit higher than their fluorinated counterparts). The emission model also highlighted that the efficacy of the non-fluorinated substances as surfactants is typically poorer than fluorinated substances and thus greater concentrations are needed within the fire-fighting foam concentrate. This means that the potential emissions are higher, particularly where the same substance is used in multiple products by different manufacturers (i.e. in aggregate).

One further important consideration therefore could be in cases where fire-fighting foams are used multiple times at the same location. The emission model suggests that the majority of use would be for training. For those substances with particularly low soil PNECs and lower biodegradation properties a concern could be that, if the control measures are less effective in some locations, releases could repeatedly 'shock' soil microflora and fauna (i.e. the release has toxic effects upon the soil, with secondary or repeated releases before the microflora and fauna communities have a chance to recover). The removal of such biological degradation pathways from the soil could also have knock-on consequences for the biodegradation of the substance itself, meaning that persistence may be greater than the values quoted within Table 5.8.

Based on consideration of these factors and in examination of the emission model alkylamidobetaine (CAS 61789-40-0) could be one such substance that meets these criteria, i.e. use concentrations (based on review of available SDS) are up to 10% w/w of the concentrate. It is used in at least four products by different manufacturers suggesting in use quantities could be significant. It also has PNEC values for fresh water of 0.0032 mg/l and soil of 0.0419 mg/kg dw (which can be considered low). In instances of sites with repeated use for training and less well-established control measures, effects for soil could highlight a need for further investigation.

6. Task 4 – Remediation costs and technologies

6.1 Introduction

The aim of this task is to determine the techniques most likely to be used for the remediation of PFAS from fire-fighting foams and fluorine-free alternatives in soil, surface water and drinking water, as well as the associated costs. In the following, the approach is briefly described before the results are presented.

6.2 Approach

A combination of inputs to the targeted stakeholder consultation (see Section 2, literature review, results of the stakeholder workshop (see Section 2.4) and expert knowledge have been used in this task.

The stakeholder workshop included a breakout group focused on remediation. This provided an overview of insights from key stakeholders and is presented first to frame the subsequent analysis. The remainder of the analysis follows a six-step approach:

- Step 1: "Remediation" and "clean-up" are defined and discussed to provide a basis for the subsequent analysis;
- Step 2: Contamination scenarios relevant to AFFF applications are reviewed with a focus on fire-fighting activities of liquid fuel fires which have been highlighted as the key use of AFFF in the market analysis. The potential for contamination resulting from use of alternative, fluorine-free foams is reviewed;
- Step 3 is a discussion on the "point of treatment" at a remediation site. The different options considered as point of treatment are source area, groundwater plume and end point treatment;
- Step 4: Applicable drivers to engage in active remediation or clean-up/treatment are evaluated;
- Step 5: While every impacted site is in some fashion unique, there are similarities related to the fate and transport of relevant PFAS compounds that produces a limited number of available and reliable remediation/treatment technologies. A more commonly used set of treatment/remediation options or a combination of those is identified and discussed in this step; and
- Step 6: The identified options are evaluated with respect to associated costs based on contamination scenarios and industry/expert knowledge.

6.3 Results

Stakeholder workshop

During the stakeholder workshop, breakout group 3 discussed PFAS remediation and associated costs and the available and feasible technologies. The following questions were presented and discussed during the workshop:

- Which technologies are most commonly/likely applied for the remediation of soil and water contaminated by PFAS or alternative fire-fighting foams?
- What are the differences in remediation practices between PFAS-containing foams and fluorine-free foams and between fire training exercises and true emergency responses?

- Are there cases where remediation is not necessary, not technically feasible or not economically viable?
- What approaches are used to manage regular run-off and storm-water run-off and what restrictions exist on discharge concentrations/volumes and treatment prior to discharge?
- Which additives, degradation-products or by-products of fire-fighting foams need to be considered, for both PFAS foams and alternatives? and
- What are the current regulatory drivers to engage in remediation (e.g. permits for training activities and discharge, Water Framework Directive EQS for PFOS)?

Stakeholders provided input on site clean-up and remediation related to PFAS as summarised by the following statements that intend to give a general perspective on remediation with respect to PFAS resulting from historical impacts at legacy sites and newly released PFAS-compounds during recent fire-training exercises or live fire events.

- Remediation at legacy sites with PFAS contamination is very difficult to address;
- Remediation costs are highly site specific;
- There is a lack of technical options for soil remediation;
- Since soil and water remediation is generally expensive, containment of fire-fighting waste water and treatment before it reaches soil and groundwater is critical; and
- Clean-up after a live event should happen as soon as possible after the incident, specifically when PFAS foams were used. Some stakeholders suggest clean-up and complex treatment is not always necessary after the use of fluorine-free foams, although due to the presence of contaminants from the fire including liquid fuel and incidental materials and compounds that were affected or released during the fire, it is often required after live incidents regardless of the foam used.

Step 1: What is what: Definition of "remediation" versus "clean-up"

Remediation

Remediation pertains to legacy contamination that historically occurred from fire-fighting or training activities using AFFF products. Remediation in this sense would only include PFAS-impacted sites, because remediation cannot be anticipated at this point for replacement substances (e.g. fluorine-free foams). It is assumed that substances that are of concern for human health and the environment, based on toxicology, fate and transport, or other legal/relevant drivers, will not be used in alternative fluorine-free foam products. Task 3 (see Section 5) has shown that the substances contained in fluorine-free alternatives exhibit lower concern than PFAS used in fire-fighting foams, due to their lower hazards and rapid biodegradation. Should fluorine-free foams become a burden in the future, and themselves require soil and/or groundwater remediation beyond the constituents of the fuels that have been extinguished, an evaluation needs to be conducted then. So far, no cases have been identified where remediation has been required due to contamination from fluorine-free alternatives.

In the use scenarios considered in this assessment, typically remediation sites include a soil source zone where the actual fire-fighting activity has been carried out. PFAS compounds present in shallow soils tend to leach with infiltrating precipitation to greater depth in the soil column eventually reaching groundwater. Once groundwater has been impacted, huge dilute plumes tend to form. Groundwater plumes are large because PFAS compounds are very mobile in the subsurface and because of the very low concentration thresholds that are relevant to human health and the environment[64]. Contaminated groundwater is in itself a concern since groundwater is a sensitive and important receptor. The critical use of groundwater can include groundwater extraction for drinking water for human consumption, for agricultural irrigation of crops, or for watering of farm animals. Groundwater can also become – directly or indirectly – surface water by extraction and surface discharge or by groundwater/surface water interaction in rivers, streams or lakes.

Typically, remedial activities are driven by regulatory processes and include the use of remediation target levels or follow a risk-based approach. The number of PFAS compounds that currently "drive the market" are few in comparison to the number of potential PFAS compounds known and likely present at a remediation site. At the same time, there are only a few PFAS compounds that are in the centre of attention based on the magnitude of their production and use, here for AFFF products. As a consequence, the number of PFAS compounds that have been researched with respect to their toxicology, fate and transport in the environment, and effects on human health and the environment is relatively small. Only about a couple dozen individual compounds have been sufficiently studied. In many European countries, there are only a few PFAS compounds that are regulated with respect to their allowable concentrations in drinking water, ground water, surface water and soil[65]. In December 2019, the European Commission and European Council agreed to set parameters for PFAS under the Drinking Water Directive (98/83/EC). Member States will be able to choose either a parameter of 0.1 µg/l for the sum of PFAS listed in Annex III of the Directive, or of 0.5 µg/l for the totality of PFAS once technical guidelines for monitoring this parameter are developed. To address concerns related to groundwater, a pilot exercise was launched in 2017 which resulted in ten PFAS being added to a "list facilitating Annex I and II review" (a list of possible substances to be considered for additional regulation in the future review of the Groundwater Directive annexes) and two PFAS to be added to a first voluntary watch list.

Clean-up

Clean-up relates to new incidents or accidents such as planned training activities or emergency response actions, respectively. Currently, it should be assumed that training activities with PFAS-containing foams are largely conducted at fully contained training facilities so that fire-fighting water can be completely captured and addressed with thorough treatment, as discussed in Section 5.3. However, there might be exceptions where release to the environment from training occurs, and there are still emergency responses where AFFF material is used. Clean-up of an emergency response site would need to happen as soon as possible after the fire is controlled and the site is safe to enter to reduce the potential or the amount of PFAS able to infiltrate into the soil matrix. Environmental sampling from affected soil and/or water (surface water and/or groundwater) might need to occur to determine follow-on actions to remove unacceptable concentrations.

The potential processes and technologies used for remediation and clean-up are discussed further in Step 5 ("Treatment technologies and treatment scenarios – soil and water") below.

[64] ITRC Fact Sheet; Environmental Fate and Transport for Per- and Polyfluoroalkyl Substances, March 2018.
[65] Concawe Report, Environmental fate and effects of poly- and perfluoroalkyl substances (PFAS), June 2016.

Figure 6.1 Overview of "Remediation" vs. "Clean-up"

REMEDIATION

- Resulting from historical activities;
- Legacy site/area;
- Large groundwater plume;
- Additionally impacted receptors;
- Multi-year site activities;
- Can include remediation infrastructure and O&M programme;
- Very expensive; and
- Technologies used and costs highly site specific.

CLEAN-UP

- Resulting from recent activities;
- Often still operating site;
- Impact initially "only" surficial;
- Contaminants geographically confined;
- Can be accomplished in short timeframe;
- Engineered systems/facilities possible, mobile equipment possible;
- Reasonable costs (much lower than remediation costs);
- Technologies used and costs more plannable; and
- Costs fuel and foam driven.

Step 2: Contamination scenarios: PFAS-containing foams and fluorine-free foams

PFAS-containing foams

For PFAS-containing foams at legacy sites, contamination patterns normally include soil, both unsaturated and saturated, to be impacted by PFAS at higher concentrations, because the PFAS entry point into the subsurface occurs from above ground in most scenarios, specifically for fire-fighting and training events. PFAS leaching to greater depths in the soil column by infiltrating precipitation eventually reaching groundwater is commonly observed at legacy sites. Leaching is supported by the physicochemical characteristics of PFAS. PFAS in shallow soils can also be transported via overland flow by storm water run-off during precipitation events. Storm water would either infiltrate into the ground at an area geographically separated from the original fire-fighting activities, or storm water run-off can directly discharge to a surface water body such as a river, stream, or lake, or it can be captured in a storm-/ waste water treatment facility. Historically, storm- or waste water facilities were not required to analyse for PFAS compounds. It can be assumed that most PFAS have passed untreated through a treatment works without awareness of the operator allowing for PFAS to spread to the wider environment[66].

The PFAS-laden soils in the source area continue to be an emission source for groundwater contamination for many years, if not decades. Once PFAS-compounds have reached the aquifer or a water-bearing unit, those compounds tend to migrate laterally and in a hydraulically downgradient direction with limited retardation from the soil matrix and negligible, if at all occurring, breakdown through biotic or abiotic processes in the aquifer[67]. As a consequence, PFAS tend to generate large plumes in groundwater. Acceptable PFAS threshold concentrations are extremely low, and plumes can be many kilometres long. In the Veneto region, Italy, a PFAS-production facility contaminated an area spanning more than 200 square km^2[68]. Various scenarios can result from PFAS-impacted groundwater. Groundwater could be extracted and used as drinking water. Extracted groundwater could also be used for irrigation of agricultural land. In addition to soil and groundwater impacts, surface water could be impacted from historically contaminated soils by means of surface water run-off. Under certain hydrogeological conditions, groundwater can become surface water or interact with surface water in brooks, creeks, streams, or river beds. PFAS-contaminated surface water is a major concern under the Water Framework Directive with an extremely low Environmental

[66] Nordic Council of Ministers, The Cost of Inaction – A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS, 2019.
[67] Concawe Report, Environmental fate and effects of poly- and perfluoroalkyl substances (PFAS), June 2016.
[68] World Health Organization, Keeping our water clean: the case of water contamination in the Veneto Region, Italy, 2016.

Quality Standard (EQS) for PFOS (annual average EQS for PFOS is 0.65 ng/l)[69]. PFAS-impacted ground or surface water can become a challenge when they enter a water treatment works at privately owned locations (e.g. oil and gas sites or airports) or public treatment works, as indicated above. In most cases PFAS are not analysed for in water treatment works and the presence or absence of PFAS are consequentially unknown. PFAS would require in most, if not all, cases, a separate treatment step in the water treatment works with potential requirements for additional pre-treatment (e.g. high dissolved organic carbon (DOC) can be a problem in treating PFAS) and retrofitting of the treatment works at a substantial cost.

Fluorine-free foams

Based on the definition of "remediation" and "clean-up" there would not be a remediation scenario that includes fluorine-free foam compounds as of now. For one, replacement products are fairly new to the market and possible/potential impacts from fluorine-free foams to the wider environment has not yet caused adverse effects. The current expectation is that replacement products (alternatives to AFFF) do not have the potential to contaminate soil and/or groundwater in a way that remediation can be assumed or predicted to be needed. The analysis of alternatives (see Section 7.5) has shown that the substances contained in shortlisted fluorine-free alternatives (i.e. a set of alternatives considered likely to be used) exhibit lower hazards than PFAS and rapid biodegradation. Even if those alternative substances have the potential to contaminate soil and groundwater, remediation scenarios/technologies are hard to define. Remediation in most EU countries is risk-driven. That risk from alternative products cannot reasonably be anticipated at this point to develop a "remediation scenario" including treatment technologies and associated costs.

There was anecdotal evidence presented by one stakeholder at the workshop that fluorine-free foam caused emulsification of the run-off water in a water treatment works. Should emulsification be a recurring issue for use of fluorine-free foams, then a separate treatment step to break up the emulsion would need to be included at the water treatment works as a retrofit at an additional cost.

Also, an anecdotal example was presented from another stakeholder that a permit was granted where 5,000 litres of firewater runoff from fluorine-free foams could be discharged directly to a sewer after "only" a fuel separator step.

Step 3: Point of treatment – source area, site hydraulic control, plume, and "end-of-pipe"

As described previously under fire-fighting scenarios using AFFF-containing products, PFAS compounds experience a fate and transport that can be generalised for most occurrences and described as follows (see figure[70] below).

At the location of the active fire-fighting activity PFAS-laden waters enter the subsurface resulting in PFAS-impacted soils – the source area (No. 1). The source area typically holds the greatest PFAS mass. Precipitation supports leaching of PFAS compounds in the unsaturated soil column to greater depth (No. 2) in the soil column eventually reaching groundwater which is then the starting point of a PFAS plume in groundwater (No. 3). Depending on the fuel that was extinguished, PFAS have a tendency to accumulate with free phase products[71] at the water table intersection. The plume will extend in the direction of and grow with groundwater flow as more PFAS-mass leaches from the source area. Eventually the plume might grow to a size extending past the property boundary (airport, O&G refinery, etc.) migrating off-site. The PFAS plume size might have grown in size and extended into areas where groundwater extraction could occur for domestic (No. 9), commercial or public use (No. 10) including private drinking water wells, agricultural

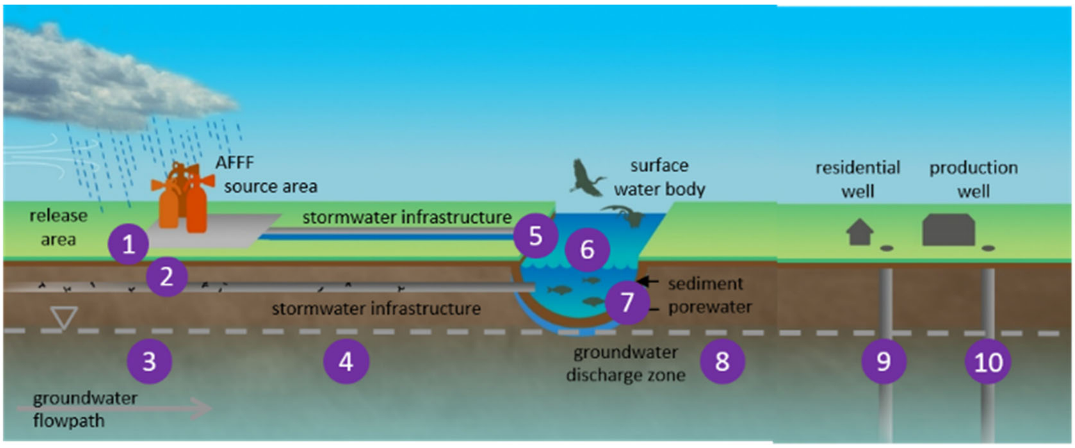
[69] Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy.

[70] Wood E&I Solutions, 2017.

[71] Common petroleum hydrocarbon-based fuels are lighter than water (light non-aqueous phase liquids – LNAPL) and accumulate at the water table intersection when they are released to the environment at large enough quantities. "Free phase" refers to a fuel layer on the groundwater table.

irrigation and livestock feeds, and drinking water production facilities. Stormwater runoff from a fire training area or live fire incident can migrate in various directions predominantly following land surface morphology (No. 5). In consequence, surface water runoff can spread PFAS contamination in directions beyond groundwater flow. Stormwater runoff can directly or indirectly occur via some sort of controlled or uncontrolled overland flow or through underground utilities. Damaged/leaking utility structures can be locations where PFAS could enter the subsurface at a point that is in only limited relation to the actual firefighting area. Stormwater or surface runoff could eventually discharge to a surface water body such as the sea, a lake or pond, or a stream, river, creek or brook (No. 6). Sediments at the bottom of surface water structures including the surface water runoff ditches, drains, channels, ponds, lakes, or the sea can have PFAS-laden sediments as precipitated solids as part of the surface water feature (No. 7).

Figure 6.2 Overview of PFAS fate and transport from use of fire-fighting foams



1. Surface soil
2. Subsurface soil
3. Source area GW
4. Downgradient GW containment
5. Stormwater infrastructure containment
6. Surface water
7. Sediment
8. Offsite GW impacted by surface water
9. Residential well GW treatment
10. Production well GW treatment

The point of treatment can be selected based on economic considerations. The investment in Euros spent per mass unit of PFAS removed is largest in the source area (No. 1). The absolute PFAS mass removed is greater in the source area when comparing to groundwater extraction and subsequent treatment. Also, PFAS mass removed in the source area will not be available to support plume growth in groundwater. The point of treatment can also be based to protect a sensitive receptor such as a drinking water (domestic No. 9, commercial, or public No. 10). Here an end-of-pipe technology would treat the PFAS-impacted and extracted groundwater to acceptable levels prior to use or distribution. Hydraulic control of a site could be critical to prevent contaminants to extend beyond the property boundary (No. 4). A series of extraction wells or a drainage wall/trench near the property boundary would ensure that PFAS-impacted groundwater does not extend beyond the property boundary by groundwater flow. The extraction well gallery or drainage would need to be installed perpendicular (as far as possible) to the groundwater flow direction and be long enough to cover the plume width. In most, if not all, cases, remediation of an entire PFAS-plume in groundwater is economically not viable since PFAS plumes are extremely large and, in comparison to other contaminants such as hydrocarbons or chlorinated solvents, they are a concern at very low concentrations.

Source area treatment: Unsaturated and saturated soils are typically treated/remediated by means of excavation and disposal / incineration. Here the largest PFAS mass is typically removed from the subsurface in a short amount of time with a high effectivity, efficiency and potentially long-lasting reduced environmental impact (depending on the end disposal route, e.g. if the leachate from the landfill is correctly collected and treated or if the incineration uses temperatures high enough to reliably destroy PFAS).

Hydraulic site control: To eliminate off-site migration of PFAS-contaminated groundwater, impacted groundwater is extracted at the site boundary through one or more extraction wells or a drainage structure. The extraction process eliminates or greatly reduces the mass flux across the property line. While the hydraulic containment system is not able to recover PFAS-impacted groundwater that has already migrated to off-site areas, it can greatly reduce the potential impact on receptors that could be downgradient, including neighbouring properties or sensitive points of use such as private or public drinking water wells or agricultural use wells or surface water structures.

"End-of-pipe" treatment: In the event that PFAS contaminated groundwater is extracted for human use or consumption or for agricultural use, groundwater would need to be treated after extraction. Commercially available treatment technologies to recover PFAS molecules from water include adsorption technologies such as granular activated carbon (GAC) or resins (regenerable and non-regenerable). Reverse osmosis can also be used to treat extracted groundwater.

Short-chain PFAS can be more resilient to some of these treatment technologies, so that more rigorous measures are required for effective treatment (e.g. a secondary treatment step using a resin that is optimised to retain the specific short-chain PFAS compounds, or higher temperature incineration). This is discussed in more detail in Step 5 on treatment technologies.

Step 4: Drivers for active measures – why is clean-up / remediation required?

For PFAS-containing foams, specifically at legacy sites with historical releases/impacts, remediation is warranted and likely required by regulatory agencies when sensitive receptors (including groundwater) are threatened or already impacted. Guidance levels for up to a dozen or so individually identified PFAS compounds (including PFOS, PFOA, PFHxS, etc.) have been developed in various European countries[72,73] and parameters for the sum of certain listed PFAS (0.1 µg/l) for the totality of PFAS (0.5 µg/l, once technical guidelines for monitoring this parameter are developed) have been developed for the Drinking Water Directive. For legacy sites in various European countries a risk-based remediation approach would be implemented by describing the risk to relevant receptors based on analytical data collected from environmental media such as soil, surface water and/or groundwater. In some instances, animal/fish or vegetation samples are collected and analysed to evaluate PFAS migration in the food chain at different trophic levels. If a risk to a receptor is not acceptable, active measures would need to be initiated. The level of effort related to an active measure and the measure or combination of measures itself is highly site specific and depends on the level of impact to the site and the sensitivity of the impacted or threatened receptor, amongst other drivers. Case studies on "contamination from use of aqueous film-forming foams" are presented in the report of Nordic Council of Ministers[74] and summarised in the table below.

Table 6.1 Nordic Council report case studies of PFAS contamination from AFFF use

Site	Contamination	Contamination source
Kallinge-Ronneby Military and Civilian Airbase, Sweden	Detected PFAS contamination in the outgoing water from one of two municipal waterworks which supplied water to around 5,000 people. PFHxS, PFOA and PFOS were sometimes 100–300 higher in the contaminated water source (e.g. up to 8,000 ng/l for PFOS). Blood samples showed significant human exposure via drinking water.	The source of the contamination was identified as the fire drill site located in the nearby military airport where AFFF containing PFOS had been used since the 1980s, then other PFAS-based AFFF since 2003 and fluorine-free foams since 2011.

[72] Concawe Report, Environmental fate and effects of poly- and perfluoroalkyl substances (PFAS), June 2016.
[73] NICOLE, PFASs Summary, January 2016.
[74] Nordic Council of Ministers, The Cost of Inaction – A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS, 2019.

Site	Contamination	Contamination source
Jersey Civilian Airport, Channel Islands	78 properties were within the plume area. Groundwater in 36 of these properties tested positive for PFOS. Although at some of the sites, concentrations of PFOS have shown signs of decline, they have remained at high levels for seven years in private wells (up to 98,000 ng/l).	The airport's fire-training site was identified as the origin of the contamination. In 1991, the fire training site started using AFFFs to meet the requirements of UK Airport Fire Services. The foam used at the site during training exercises was discharged regularly without monitoring, dissolving into the ground and rainwaters. Contamination subsequently found its way into the aquifer and bay.
Schiphol Airport, The Netherlands	In July 2008, an error in the sprinkler-system at a hangar released 10,000 litres of AFFF, containing 143 kg of PFOS, into the surrounding environment. This fed into a larger reserve of waste water (100 million litres) kept in five reserve reservoirs, several of which leaked and caused substantial contamination of the soil and surface water. The water resources were found to contain over 12 times the average amount of PFOS otherwise found in several reference sites in the Netherlands.	

Source: Nordic Council of Ministers, The Cost of Inaction – A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS, 2019.

Clean-up is driven to a large degree by the flammable liquid itself, the soot, water and "dirt" in general terms that contribute to the fire-fighting water runoff and its potential to impact the environment. The foam used might just be another component that will need to be captured and treated, specifically under the scenario of a fluorine-free foam use. As discussed above, it is assumed that fluorine-free foams will not be persistent, mobile and toxic at levels that will require remediation (e.g. legacy site) when they enter the environment. For training activities facilities including the associated water treatment works should be engineered to account for 100% collection of all fluids including fuel and foams that the fire training water can be cleaned and treated accordingly before releasing treated waters back to the larger environment. Should a fire have been extinguished during training or a live event using AFFF foam then it is advisable to clean-up the firefighting water promptly after the incident. Depending on the location of a live fire and the foam used, soil samples should be collected from areas where fire water runoff could have percolated into the subsurface to evaluate the presence or absence of PFAS compounds and their concentrations. Depending on the soil analytical results a need for soil exchange might be indicated. After a live fire event, regulatory communication and agreement is required for subsequent steps in the clean-up procedure to reach acceptable site conditions that will not create or leave a risk to human health or the environment.

One stakeholder shared a scenario where clean-up seemed to be challenging. Fire-fighting activities in close vicinity to open water bodies (such as sea or lake) make it close to impossible to recover fire-fighting water runoff discharged into the sea or lake. To avoid runoff entering the sea, engineering solutions would be required as much as that is possible. For facilities in close proximity to large water bodies, one could possibly design berms and a drainage system to recover fire-fighting water in case a fire should truly occur. However, it might also be prudent to switch to less environmentally critical, fluorine-free, foams.

Step 5: Treatment technologies and treatment scenarios – soil and water

Treatment technologies[75]

Remedial options or treatment technologies available to address PFAS contamination are limited based on the specific physicochemical properties of these compounds. Many of the commonly used remedial

[75] ITRC Factsheet, Remediation Technologies and Methods for Per- and Polyfluoroalkyl Substances, March 2018.

treatment technologies are not effective because of the low volatility, and the molecular stability resisting oxidation, reduction or microbial degradation.

Current full-scale proven and reliable remediation technologies are limited to the following[76]:

- Soil:
  - Excavation followed by:
    - Landfilling; and
    - Incineration.
  - Confinement/capping.
- Groundwater:
  - Pump and Treat followed by:
    - Adsorption on granular activated carbon (GAC);
    - Adsorption on resin (regenerable and non-regenerable); and
    - Reverse osmosis (clean water application).

Commonly used **soil** remediation technologies include excavation and landfilling or incineration, and soil capping. For coarser grained soil, soil washing can be an option which is in use at sites featuring the right geological setting. However, soil washing water will require subsequent treatment, and the finer soil fraction needs to be treated in a different fashion (landfilling, incineration). **Water** treatment (including groundwater, surface water, and storm-/ waste water) typically include adsorption of PFAS compounds from the aqueous matrix onto an adsorbent such as granular activated carbon (GAC), or resins (non-regenerable or regenerable). The relative and absolute loading capacity of adsorption media for PFAS is low, requiring more adsorbent than when compared to other contaminants such as hydrocarbons or chlorinated solvents. Spent adsorbents need to be regenerated or incinerated at high temperature (>1,000 to 1,200°C). As discussed in more detail below, GAC or resin treatment can be effective for both long-chain and short-chain PFAS, but they are less efficient for short-chain PFAS.

Soil **excavation and landfilling** does not destroy the actual compounds of concern, but rather shifts the problem to a different geographic location. Landfilling includes hauling PFAS-impacted soils via truck or in limited instances on rail or boat to a landfill. Transport is energy consuming and bears its own risks such as accidents leading to spilling PFAS-contaminated material. Landfill space in Europe is becoming increasingly more limited because it contradicts environmental policy objectives to landfill impacted soils and permitting of new landfills lags behind required capacities. Also, landfills that accept PFAS-impacted soils need to address PFAS in landfill leachate which requires monitoring and in consequence some sort of water treatment technology for PFAS in the leachate. Regular landfills are reluctant to accept PFAS-containing soils, and disposal costs increase accordingly for landfills accepting PFAS-containing materials.

Incineration of soils is an energy intensive process, furthermore due to the very stable C-F bond in PFAS, incineration of PFAS contaminated soil requires temperatures of at least 1,100°C to degrade PFAS to carbon dioxide and hydrogen fluoride[77], however, also note that shorter chain PFAS (C4) are even more resilient (than longer chains) and need higher temperatures closer to 1,400ºC to achieve full breakdown. For incineration at temperatures below 1,100ºC it has not yet been determined what is produced from incineration of PFAS[78]. However, this combination of technologies (excavation and then landfilling or

[76] Discussed technologies were highlighted at the stakeholder workshop and are also based on expert assessments such as NICOLE and Concawe. The number of full-scale proven or commercialized technologies is still limited for PFAS.
[77] UNEP, 2012 in: https://www.kemi.se/global/rapporter/2016/report-11-16-strategy-for-reducing-the-use-of-higly-fluorinated-substances-pfas.pdf
[78] https://www.kemi.se/global/rapporter/2016/report-11-16-strategy-for-reducing-the-use-of-higly-fluorinated-substances-pfas.pdf

incineration) are proven technologies to address source zone remedial needs at the site level. Capping PFAS-impacted soils reduces or eliminates the potential of precipitation leaching PFAS compounds from soil to groundwater. While capping does not remove or destroy any of the contamination it allows for an effective management of emission reduction from the soil body. Soil caps could include an engineered cap as commonly used in landfill scenarios. Engineered caps utilising for example clay will require monitoring and potentially maintenance work to be conducted when the cap degrades over the following years or decades.

Immobilisation of PFAS is another potential treatment technology to treat PFAS-contaminated soils. Most immobilisation procedures are applied to soils that have been excavated (ex-situ). Immobilisation aims to reduce leachability of PFAS compounds when coming in contact with water such as from precipitation. Immobilisation can be accomplished through solidification or stabilisation. To achieve stabilisation products such as RemBind™ or MatCARE™ can be used. Bench-scale or pilot testing are required to confirm desired performance parameters of the products. With immobilisation/stabilisation technologies the contaminant itself has not been destroyed but rather reduced in its mobility in soil. There is no or only limited long-term field experience with the longevity of the immobilisation. At the end, immobilised and disposed of/landfilled soils will require monitoring to confirm continued immobilisation and allow for corrective action should PFAS leaching occur.

Pump and Treat (P&T) is a standard technology utilised in contaminated land management practice to extract impacted water from the subsurface. Water extraction can be accomplished through individual wells equipped with down-well pumps that deliver the water to the surface where subsequent treatment can take place. Extraction of groundwater can also be accomplished through engineered and constructed drainage features. A drainage wall consists of a linear structure mostly perpendicular to groundwater flow extending into the groundwater table to a depth equal to or greater than the impacted water-bearing unit. Part of the drainage wall/structure also is an extraction well or vault to collect and pump water to the surface. The drainage wall is constructed of material featuring a grain size greater than the surrounding soil material so that the drain itself has a higher/better hydraulic conductivity thus allowing groundwater to preferentially flow into and inside the drainage structure.

Groundwater that has been extracted from the subsurface is transferred via pumps into a treatment unit that customarily includes pre-treatment steps followed by the actual PFAS-treatment technology. Most pre-treatment steps include addressing geochemical limitations/challenges necessary to be addressed for the actual subsequently-occurring PFAS removal to work optimally. This could include iron precipitation, settlement tanks for fine material, removal of "other" total or dissolved organic matter that could compete during PFAS adsorption, specifically on GAC, or other co-existing contaminants that require treatment such as heavy metals.

In typical environmental applications today PFAS removal from the water stream occurs through an adsorption technology. Adsorption media include GAC, regenerable resins, and non-regenerable resins. **GAC** can originate from a variety of sources and actual products are many. Ideally bench-scale and/or pilot testing would be conducted to identify the optimal GAC for adsorption of the PFAS mix present in water for the specific project.

Bench-scale and/or pilot testing would also be done to identify a suitable **resin** to treat PFAS-containing waters. For the resin the selection of a non-regenerable or a regenerable product must be made. Non-regenerable resins would adsorb more PFAS mass absolute per unit of resin when compared to regenerable resins. However, non-regenerable resins once spent need to be dealt with off-site either in a landfill or through destruction via high-temperature incineration. Ion-exchange resins contain positively charged and resin-bound functional groups that stoichiometrically bind negatively charged ions such as PFAS anions. Functional groups that form the exchange unit for PFAS can be tailored to fit certain PFAS mixtures as they are generally observed in groundwater contamination. Resins are suitable for high flow rates and low concentrations. Upon exhausting the exchange capacity of the resin, regenerable resins can be back-washed with sodium chloride solution, ethanol, (hot) water or other benign solvents. Resin regenerate is a low-volume concentrate with high PFAS concentrations that will need to be addressed. High temperature incineration is one option to destroy the PFAS molecules in the regenerate. It is advisable to test the optimal exchange/adsorptive media for water treatment on a site by site basis. Not only water geochemistry but also secondary considerations might be critical to the selection of the optimal treatment media.

The treatment of longer chain (>C8) PFAS molecules using adsorbing technologies such as GAC or resins works with a higher efficiency than parallel treatment of shorter-chain PFAS (<C8) molecules. Longer-chain PFAS molecules preferentially adsorb to GAC and/or most resins. For the effective treatment of longer- and shorter-chain PFAS molecules, it might be necessary to preferentially target in a first treatment step the longer-chain PFAS molecules, for example using GAC. GAC retains longer-chain PFAS molecules with a higher efficiency resulting in an "early" breakthrough of shorter-chain PFAS compounds. These compounds will need to be treated with a follow-up secondary treatment step such as a (regenerable or non-regenerable) resin. This second adsorbent can be optimised to retain the specific short-chain PFAS compounds. Diligent monitoring of individual PFAS-compounds' concentrations is important to maintain process control and optimal treatment conditions including change out of GAC or resin. It is important to conduct bench-scale testing or even field pilot tests to evaluate and discern the most effective and cost-efficient treatment technologies or combination of treatment technologies for the PFAS-mix existing at each site.

Reverse osmosis is a filtration technology that includes a semi-permeable membrane to remove ions, molecules or larger particles. Water to be treated is forced under pressure to pass through a membrane where the purified water passes through the membrane which rejects ions and unwanted compounds as solute on the pressure side of the treatment process. For PFAS treatment the low-volume solute would contain the PFAS compounds and other rejected ions and molecules. The solute is a concentrate which requires further treatment such as incineration. Reverse osmosis is generally applied in pure water applications to produce potable water. Reverse osmosis is normally not used in contaminated land applications where general water quality and chemistry is more complex, diverse and challenging. Research shows that these types of membranes are typically more than 90 percent effective at removing a wide range of PFAS, including shorter chain PFAS[79]. The use of RO membranes is a widely accepted filtration technique. One study reports use of thin film composite polyamide RO membranes, where 99% removal of PFOS was achieved with several types of membranes at concentrations >1 mg/l. RO is normally used in the drinking water industry for removal of PFAS and other contaminants[80]. The relevant factor in effective and efficient RO treatment is described to be the pore size of the membrane used in the filtration process[81].

Additional groundwater treatment technologies exist. Research and development have been underway for several years now to study PFAS destruction technologies that fully mineralise PFAS compounds. Complete destruction of PFAS molecules seems to be the best approach to end the commercial and environmental liability associated with PFAS contamination. While there are a few promising technologies, none of those are quite field ready at full-scale or the commercial level. These technologies include ozonation, chemical oxidation, electrochemical oxidation, plasma destruction, and sonochemistry. These technologies are only referenced here but not further discussed since (longer term) full-scale data are still missing and experience with costs and treatment performance is not available. Very recently a soil bacterium was described as having the demonstrated ability to break down PFAS molecules. While the bacterium has successfully degraded PFAS under laboratory conditions, field applications, if ever possible, are likely years away. Nevertheless, successful application of microorganisms in in-situ applications would be a cost-effective, efficient and sustainable approach to address PFAS contamination.

[79] https://www.epa.gov/sciencematters/reducing-pfas-drinking-water-treatment-technologies

[80] Concawe Report, Environmental fate and effects of poly- and perfluoroalkyl substances (PFAS), June 2016.

[81] Rahman et al., Behaviour and fate of perfluoroalkyl and polyfluoroalkyl substances (PFASs) in drinking water treatment: A review, Water Research 50 (2014) 318 – 340.

Treatment scenarios

Subsequently, scenarios have been developed for a legacy site remediation and for a live event emergency response clean-up both including AFFF, i.e. PFAS compounds as driver substance.

Fire training areas should be designed and engineered facilities that allow for a 100% capture of materials used in the training activity. Captured fluids from training activities should run through a series of designed and engineered treatment steps that could include a sediment trap, an oil/water separator and possibly a granular activated carbon filter before discharge. In training scenarios with AFFF foams the GAC filter might have to be larger sized and might require more frequent change out to address the limited loading capacity of PFAS on GAC.

Emergency responses at airports, refineries or other large facilities housing or handling large volumes of flammable liquid fuels that include use of AFFF products will need to capture firefighting water as soon as practicable and safe. The combined fluids and solids that result from a live fire event need to be captured, collected and separated in relevant fractions and further processed. In general, should AFFF foams have been used in the fire-fighting effort, all waste streams could be potentially contaminated with PFAS. Professional judgement or analytical testing will provide information to render recommendations for subsequent handling and/or disposal of individual waste streams. For retained and collected fluids, a variety of treatment steps could be required to separate phases (fines/solids vs. liquids; oil vs. water) such as sedimentation tanks and an oil/water separator. The separated aqueous phase will require treatment to reduce total petroleum hydrocarbons (TPH) and PFAS concentrations, and possibly also other compounds, depending on the incident. Temporary storage of captured firefighting waters in large size tanks is advisable to characterise the water via laboratory analysis. Based on laboratory results, an appropriate treatment unit or treatment train can be configured and delivered to the site for (batch) treatment of the captured and stored water.

For **legacy sites** requiring active remediation measures, risk-based decision making will support a remedial approach including the relevant points of treatment and the combination of applied technologies to reduce the risk from the site to an acceptable level. In very general terms this could include source area treatment via soil remediation (as discussed above) and hydraulic containment of the site. In addition, there could be additional treatment of impacted receptors at the point of use via an "end-of-pipe" approach which in most cases includes adsorption of PFAS or use of reverse osmosis. It seems economically not viable to decontaminate the entire PFAS groundwater plume associated with a legacy site. The larger PFAS plume itself will likely become a socio-economic burden for future generations needing to deal with existing PFAS background levels.

Step 6: Cost of remediation / treatment: soil and water

Overview of approach

The following remediation cost estimates associated with legacy "PFAS sites" were developed based on market-typical unit prices for remedial activities and industry experience with these types of projects. In addition, treatment costs were discussed and provided by individual stakeholders at the workshop. Further expert organisations such as NICOLE and Concawe discuss and review remediation costs associated with PFAS legacy sites[82,83].

It also needs to be emphasised that the cost ranges presented for remediation are based on bottom-up calculations with assumed project scenarios such as volume and/or area of PFAS impacted soils, or PFAS concentrations in extracted groundwater in combination with an assumed water extraction rate for a pump and treat system.

[82] Nordic Council of Ministers, The Cost of Inaction – A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS, 2019.
[83] Nicole Working Group – Emerging Pollutants, sub-group remediation, Prague Workshop, November 2014.

While the presented costs provide a robust high-level estimate of how expensive a PFAS soil and/or groundwater remediation project might be, there are various drivers in the parameter set of site remediation that can greatly increase project costs. Site specific factors such as "other" contaminants that compete for GAC adsorption, required pre-treatment of geochemical reasons such as high iron or manganese, subsurface soils that cannot reasonably be excavated because they consist of rock, and the PFAS spectrum present in the extracted water cannot reasonably be included in cost scenarios. Hence it should be highlighted that a real project might not be as straight forward.

Also, regulatory requirements with respect to likely site-specific remedial target levels have a great influence on the total cost, because each additional concentration reduction of treatment target levels increases (eventually exponentially) the associated costs per unit of water treated or the volume of soil that needs to be excavated and disposed of.

The estimated remediation costs also do not reflect a full site decontamination but include rather a measure or combination of measures that reduces the risk emanating from the impacted site to an acceptable level of risk for human health and the environment under a general site use scenarios.

The estimated costs were compared in a top down fashion with existing PFAS remediation projects as much as those are available for cost comparison. The costs do not include any consulting fees, bench-scale or pilot testing associated with remedial investigations / feasibility studies or remedial design and planning or monitoring requirements to confirm the selected measure to be properly functioning and reaching and maintaining the desired remedial objective. Also not included in the projected costs are repairs or replacement of remedial infrastructure beyond what might be considered "normal" O&M activities.

A general groundwater monitoring programme is also not included in the costs. Long-term groundwater monitoring is part of a remediation project to measure plume size and stability over the course of the ongoing project. Specifically, when a full decontamination has not been part of remedial action, long-term monitoring confirms successful implementation of selected measures such as a pump and treat system. For the various reasons stated above, the following estimates should be considered "rough estimates" that provide order-of-magnitude cost ranges associated with PFAS remediation.

Soil

For the scenario "soil excavation and landfilling" and "soil excavation and incineration", a volume range for the impacted soil volume that needed to be excavated was estimated to be between "30m by 30m by 3m deep" and "75m by 75m by 5m deep" as conservative lower and higher values. It is very possible that there will be smaller or (much) larger excavation areas/volumes, but those would rather be on the edge of the likely spectrum. For excavation and landfilling, the absolute concentration or the PFAS compound spectrum does not play an extremely critical role, specifically for "excavation and incineration" because it does not impact the unit costs for treated soil.

Typical transportation costs for excavated PFAS-laden soils to the landfill or the incineration facility are included in the unit costs. These transportation costs will change project by project based on the distance of the project site to the landfill or incineration facility or the difficulty to reach the excavation area.

For the soil capping scenario, the same source area footprint range (30m by 30m; and 75m by 75m) was used for cost comparison with the excavation options. Cap construction includes prepping of the site and installation of geotextiles to eliminate meteorological water percolation through the PFAS-impacted soil volume. The geomembrane is covered with a 30 to 50-cm thick layer of compactable, clean soil cap. For the scenario of "soil capping", monitoring of the soil cap is required, together with associated maintenance and repair work, as needed, plus a groundwater monitoring programme to document the effectiveness of the soil cap with respect to vertical PFAS migration and desired emission reductions from the capped soils to groundwater. This groundwater monitoring program is cap-specific and does not include a site- or plume-wide groundwater monitoring programme. For the monitoring programme, a 10-year, a 20-year, and a 30-year scenario were calculated. However, in reality, the soil cap and groundwater quality need to be monitored for as long as the PFAS-laden soils remain at the site. Possibly at one point in time the monitoring frequency could be reduced if trends and concentrations in groundwater are stable enough.

One workshop stakeholder reported costs for soil incineration in the range of €400 to €600 per ton.

Table 6.2 Cost estimation of soil remediation

Technology	**Capex (Unit Costs)**		**Opex (Unit Costs)**		**Source Area Volume** **30m x 30m by 3m deep to 75m x 75m by 5m deep**		
	Low	High	Low	High	Construction Cost		
Excavation and off-site disposal	€100/t	€350/t	---	---	€0.5 – 18 million		
Excavation and incineration	€500/t	€750/t	---	---	€2.5 – 38 million		
Capping					Construction + 10 Year M&M	Construction + 20 Year M&M	Construction + 30 Year M&M
Cap construction	€75/m²	€150/m²	---	---	€0.07 – 0.85 million	€0.07 – 0.85 million	€0.07 – 0.85 million
Cap monitoring and maintenance	---	---	€10,000/ year	€50,000/ year	€0.10 – 0.5 million	€0.20 – 1.0 million	€0.30 – 1.5 million
Groundwater well network (cap-specific)	€50,000	€200,000	---	---	€0.05 – 0.2 million	€0.05 – 0.2 million	€0.05 – 0.2 million
Groundwater monitoring (cap-specific)	---	---	€20,000/ year	€60,000/ year	€0.20 – 0.6 million	€0.40 – 1.2 million	€0.60 – 1.8 million
Capping - Total					€0.42 – 2.2 million	€0.72 – 3.2 million	€1.0 – 4.3 million

Capex: Capital investment cost. Opex: Operational cost over the lifetime of the measure. M&M: Maintenance and monitoring
Source: Wood estimates based on previous experience.

Groundwater

For remediation cost estimates associated with groundwater treatment, groundwater extraction with an adsorption technology was used. Costs for granular activated carbon were used for the water treatment estimates, because granular activated carbon has been used more frequently. The average water flow rate was estimated to be between 10 m^3/hr and 75 m^3/hr and with PFAS concentrations ranging between 10 µg/l and 100 µg/l. System flow rates are influenced by the width and depth of the plume that needs to be addressed and the hydrologic permeability for groundwater. PFAS concentrations in the extracted groundwater could be lower than 10 µg/l, but could also be (much) higher than 100 µg/l. As discussed above, the lower and upper values for flow and concentration are not intended as minimum and maximum values, but rather to create cost scenarios at the lower and upper spectrum of typical costs. The likelihood of lower and (much) larger costs does exist[84].

The construction of a series of extraction wells is required to provide an extraction well network that produces hydraulic control of the site at a strategic line in the field or at the property boundary or upgradient of a receptor such as a surface water body that requires protection. The network of extraction wells can be

[84] Züblin, Sonderdruck aus Handbuch Altlastensanierung und Flächenmanagement (HdA), PFC-Grundwassersanierungen: Stand der Technik und Kosten, März 2018.

replaced with a drainage wall/trench for groundwater extraction from the wall/trench. In both scenarios extracted groundwater is pumped to a treatment system that was specifically designed to address the geochemical and "other" relevant parameters that require pre-treatment before PFAS compounds can be effectively removed from the aqueous matrix. The well field needs to be connected to the treatment unit and with a discharge point after treatment to dispose of the treated water. The well field and system will need to be connected via piping, require electrical powerlines and possible remote sensing in the wells or remote telemetry to communicate malfunctioning equipment to the operator wirelessly.

For long term treatment the treatment system is likely to be housed in a specifically designed and constructed building, shed or container. Industry values for the adsorption of PFAS onto GAC or resin can be used to estimate – for these concentration and flow scenarios – how much carbon might be spent just based on mass loading capacities. As stated for soil treatment it is likely that there are legacy sites that require a smaller groundwater treatment system than that in the estimation range but likely there are also sites requiring (much) larger treatment units.

Table 6.3 Cost estimation of groundwater remediation

Technology	Capex (Unit Costs)		Opex (Unit Costs)				
	Low	High	Low	High	Construction + 10 Year O&M	Construction + 20 Year O&M	Construction + 30 Year O&M
Pump and Treat							
Well field OR drainage wall construction	€100,000 /site	€750,000 /site	---	---	€0.10 – 0.75 million	€0.10 – 0.75 million	€0.10 – 0.75 million
Infrastructure construction	€250,000 /site	€1,000,000 /site	---	---	€0.25 – 1.0 million	€0.25 – 1.0 million	€0.25 – 1.0 million
Operation and maintenance	---	---	€85,000 /year	€950,000/year	€0.85 – 9.5 million	€1.7 – 19.0 million	€2.6 – 28.5 million
Pump & Treat - Total					€1.2 – 11.2 million	€2.0 – 20.8 million	€2.9 – 30.3 million

Capex: Capital investment cost. Opex: Operational cost over the lifetime of the measure. O&M: Operation and maintenance.
Source: Wood estimates based on previous experience.

Drinking water

Reverse osmosis (RO) was included to provide a sense what cost might be included to treat impacted groundwater that is considered for drinking water use, specifically in a larger scale public drinking water works. Reverse osmosis is normally not considered appropriate for contaminated land remediation projects but rather for clean water applications that still contains impurities. Membranes of RO systems are prone to fouling when the water quality is too poor. RO is electricity intensive and leaves a rejectate that has higher PFAS concentrations which needs to be treated either over GAC filters or otherwise addressed as a PFAS-containing waste that needs to be properly disposed of.

Table 6.4 Cost estimation of drinking water remediation

Technology	Capex (Unit Costs)		Opex (Unit Costs)				
	Low	High	Low	High	Construction + 10 Year O&M	Construction + 20 Year O&M	Construction + 30 Year O&M
Reverse Osmosis							
System construction/ extension	150,000 €/site	750,000 €/site	---	---	€0.15 – 0.75 million	€0.15 – 0.75 million	€0.15 – 0.75 million€
Operation & maintenance	---	---	275,000 €/year	1.3 Mio €/year	€2.75 – 13.0 million	€5.5 – 26.0 million	€8.25 – 39.0 million
Reverse Osmosis – Total					€2.90 – 13.8 million	€5.7 – 26.8 million	€8.4 – 39.8 million

Capex: Capital investment cost. Opex: Operational cost over the lifetime of the measure. O&M: Operation and maintenance.
Source: Wood estimates based on previous experience.

For European sites the Nordic Council of Ministers report[85] describes remediation costs associated with contamination from PFAS ranging from several hundred thousand up to €40 million with one high-cost example for the Dusseldorf Airport, Germany estimating a total remediation cost of up to €100 million. In comparison to the costs provided in this report with the Nordic report remediation costs for PFAS-impacted sites (such as airports) will total from the single digit € millions to the lower double-digit € millions. For Schipol Airport 50 000 m^3 of impacted soil were removed at a cost of €600-800/m^3.

As described in previous sections there is a variability in costs for soil remediation depending on factors such as amount of PFAS spilled, presence of other contaminants, the volume of soil that has been contaminated, the type of soil, the environmental setting of the impacted site, and the receptors impacted or threatened.

In the Nordic report cost ranges are given for three airports where costs were modelled. The modelled costs included both water and soil remediation using different methods and different levels of allowable remaining concentrations. The modelled cost ranges spanned from €2.1-24 million (Kristiansand Airport) over €0.4-7.1 million (Harstad/Narvik Airport) to €0.41-8.1 million (Svalbard Longyearbyen). While the remediation technologies were not reflected in the Nordic report those costs are consistent with the estimated cost range as developed in this report.

85 Nordic Council of Ministers, The Cost of Inaction – A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS, 2019.

PART 3 – ECHA STUDY

7. Task 1: Analysis of alternatives to PFAS-containing fire-fighting foams

7.1 Introduction

This task covers the technical feasibility, economic feasibility and availability of alternatives to PFAS-containing fire-fighting foams. For any given Annex XV restriction proposal, the analysis of alternatives (AoA) is a key part of the dossier – it drives the scope of the socio-economic analysis (SEA) and is a key consideration when determining the ultimate regulatory action. The results will feed into the pre-RMOA and (pre) Annex XV dossier report. The various stages undertaken for this task are explained in more detail below.

7.2 Approach

The AoA and SEA has been undertaken in line with ECHA's guidance on the preparation of an Annex XV dossiers and with ECHA's guidance on socio-economic analysis in the context of restrictions. The AoA focuses on alternative products that could fulfil the required function delivered by PFAS in FFF.

The approach covered:

Technical feasibility. Including, but not necessarily limited to aspects such as:

- Comparison between the function provided by PFAS-containing foams and their alternatives;
- Performance (efficacy) to fight various types of fires, including liquid fuel fires ("Class B" fires);
- Required machinery/equipment/storage tanks; and
- Uses where alternatives do not meet (fully or partially) the required performance standard and why.

Economic feasibility. Including, but not necessarily limited to aspects such as:

- Annualised cost for an assessment period that takes into account the investment cycle in the industry;
- Cost difference of bringing forward investment(s);
- Required amounts/loadings of alternative foams;
- Price per litre or kg of concentrate;
- Shelf life;
- Machinery/equipment/storage tanks changes;
- Any need for specific training to use the alternative foams;
- Possible savings to users in fire-fighting;
- Training (e.g. benefits of being able to practice with the alternative foams with minimal cleaning requirement); and

- Possible immediate clean up after fire made unnecessary or less expensive.

Availability of alternatives

- Whether and when alternatives are available in the required quantities. If not, expected time to reach the necessary quantities.

Environmental and health risks of alternatives

- Assessment of inherent properties of alternatives with regard to potential environmental and health risk. The assessment includes key properties used for identification of substances of very high concern under REACH:
  - CMR (Carcinogenic, Mutagenic or toxic to Reproduction) properties - for the assessment it is investigated if substances included in the products are classified according to these properties (either by a harmonised classification or self-classification); and
  - PBT (Persistent, Bioaccumulative and Toxic) or vBvP (very Bioaccumulative and very Persistent) - information obtained from safety data sheets of the products.
- Assessment of GreenScreen® profiles of the products. A GreenScreen Certified™ Standard for Firefighting Foam has recently been published[86] and four Firefighting Foams have been evaluated following the GreenScreen® standard[87]. All are assigned the GreenScreen® level bronze. Two of the example products described in more detail in this section have been evaluated using the Greenscreen® standard.

The AoA has been undertaken in the following six steps:

- Step 1 – Literature review on fluorine-free products identified in the Commission study;
- Step 2 - Consultation of stakeholders;
- Step 3 - Preparation of shortlist of alternatives and a list of example substances;
- Step 4 - Additional information gathering and assessment of example alternatives;
- Step 5 - Assessment of illustrative cases; and
- Step 6 - Final analysis of alternatives.

7.3 Initial screening and consultation results

Task 1 of the Commission study identified all the fluorine-free alternative products currently available on the market. Information on these fluorine-free alternatives was found by conducting a wide review of the literature and market analysis of products currently manufactured and available on the market. However, this list did not tell exactly which products are currently being used in the EU and was consequently supplemented with information from the consultation responses on in-use alternatives.

The total number of fluorine-free alternative foam products identified in Task 1 (substance ID) was 168, produced by 38 different companies globally. The substances that are being used to produce these alternatives show similarities across different companies/products. A mixture of substances is typically used instead of PFAS in various percentage combinations for each of the fluorine-free foam alternatives (including solvents and surfactants) to attain the necessary foam/film forming functions of the product.

86 https://www.greenscreenchemicals.org/resources/entry/fff-standard-resource
87 https://www.greenscreenchemicals.org/certified/products

Step 1 – Literature review on fluorine-free products

The list of all fluorine free products (from the Commission study, Task 1 substance ID) acted as a starting point for the analysis of alternatives. The first step was a literature review of SDS (Safety Data Sheets), publications, reports and product data sheets for each of these fluorine free products to extract data on technical/economic properties and availability. Based on the results from the stakeholder questionnaire information relevant to each of the criteria described above were captured in a spreadsheet.

Based on these initial results, the following patterns emerged for the fluorine free alternatives.

The availability of data in the public domain indicated that:

- Most manufacturers provide information about their products via product information sheets, technical data sheets and/or material safety data sheets. From these sources, information on application ranges (e.g. sector, fire class), compliance with international performance standards and some technical parameters such as foam expansion ratio and degradation rate can be retrieved;
- More generic (not product-specific) information about the overall performance and use of alternative fluorine-free foams and their comparison to PFAS-containing foams is available from reports published by public agencies, in the scientific literature, opinion and marketing articles from industry stakeholders. However, these often do not provide the level of detail required on the technical and economic feasibility of specific alternative products;
- According to the manufacturers' specifications, fluorine-free foams are available for both class A and class B fires. Some products, e.g. Expandol from Angus Fire or Ecopol from Bio-Ex are specified for use for both class A and B fires depending on concentration and application method;
- Fluorine-free foams are either recommended as low, medium or high expansion foams[88], or the same product can be used with different expansion ratios depending on use concentration and equipment, e.g. the H-930 synthetic multiexpansion foam concentrates from Auxquimia;
- Some literature reviews (e.g. the IPEN position report by Allcorn et al. 2018) suggest that fluorine-free foams are viable alternatives to PFAS-containing foams across many sectors, however there is no general consensus to suggest that a single type of foam meets all needs encountered by end users; and
- Liquid fuel fires of large atmospheric storage tanks[89] require foams capable of flowing on large burning liquid surfaces and sealing against hot metal surfaces to prevent reignition. The development of suitable test criteria for large storage tanks and fluorine-free foams is still ongoing under the LASTFIRE project[90].

A list of the international standards, and the available information on the compliance criteria for these standards is provided in Appendix 5. Please note that a single product can be compliant with multiple UL/ICAO/EN standards. The European Standards of EN 1568 Part 1-4 test foam products for both extinguishment and burnback performance on liquid fuel fires for both non-polar (Part 1-3) and polar, water-miscible (Part 4) fuels. The EN 1568 is not a pass-or-fail standard; products are allocated grades of

[88] The expansion ratio is the ratio of volume of foam formed to the volume of solution used to generate the foam. As an example, an 8:1 expansion ratio means 800 l of finished foam were created from 100 l of foam solution. High expansion foams have an expansion ratio in the range 200:1 to 1000:1, medium expansion foam have an expansion ratio in
the range 21:1 to 200:1 and low expansion foam have an expansion ratio in the range 2:1 to 20:1 (as defined by the US standard NFPA 11 and NFPA 11 A).

[89] There is no specific definition of a "large" storage tank. The LASTFIRE projects used a 100 m^2 (ca. 11 m in diameter) and 10 m high tank to perform a large scale test. Tests with tanks with diameters of 30 m or even larger are recognised as ideal tank sizes to simulate realistic conditions, but such tests are also assessed to be too expensive to conduct.

[90] http://www.lastfire.co.uk/default.aspx?ReturnUrl=%2f

performance, i.e. for Part 3, Grade 1-4 is used for extinguishing performance and Grades A-D for burnback resistance. For Part 4, Grade 1-2 for extinguishing performance and Grades A-C for burnback resistance. Grade 1A is the highest achievable grade for both tests. As shown in the examples below, alternatives are available with the A1 grade for both Part 3 and Part 4.

Step 2 - Consultation of stakeholders

Information gathered on fluorine-free alternative products from data sheets and the literature review was supplemented with the stakeholder consultation responses.

The consultation questionnaire used to gather information from targeted stakeholders (see Section 2) was designed to help gather information to feed directly into the delivery of this task, specifically:

- Specific alternative foam products, the chemical identity of these products, and whether these are currently on the market in the EU;
- Availability of alternatives, including the volumes produced, sold, used; and key trends and drivers;
- Technical feasibility of alternatives, i.e. compliance with performance standards, differences in volumes and frequency of use required; and
- Economic feasibility of alternatives, e.g. the costs of changing equipment, the saving through avoided remediation.

In total 33 written responses were received for the targeted stakeholder consultation. Of these, 19 provided information on alternative foam products.

These responses included input from individual manufacturers, users of foams (from airports, oil and gas industry, and chemical facilities), national authorities and academic/training professionals. Of these, 17 responses provided details of specific 'alternative' products available.

In addition, input was received on alternatives in general, for example from the responses of key trade associations (both EU and US), as well as previously published reports and analyses from national authorities[91], research and testing information[92], and special interest groups[93].

The responses received from stakeholders have generated useful information that has fed into and enabled the AoA. A brief summary of the observations from the analysis of the consultation responses is provided below.

- In terms of the chemical identity of alternative products, in most cases, where alternative foam products were named, the specific chemical components were either not known or not divulged (e.g. citing trade secrets). In some cases (e.g. Bio-Ex's 'BIO' foams, and Auxquimia's EE-3 foam), the general class of chemicals was indicated, and in some cases (e.g. AngusFire products), the specific chemical components were named. Where possible, the information provided on chemical identity has fed into the overall AoA for this study;
- In terms of availability of alternatives, from the responses received as part of the consultation, ~80 specific products currently in use were identified. The specific foam products identified in the consultation responses are provided in the table in Appendix 6. As a preliminary check of these products, we cross-referenced those identified with the list of substances in Section 3 (Substance ID). The vast majority of the specific products indicated to be in use from the

[91] KEMI (2015) Chemical Analysis of Selected Fire-fighting Foams on the Swedish Market 2014
[92] Published testing data, as provided by LASTFIRE: www.lastfire.co.uk/
[93] IPEN (2019) The Global PFAS Problem: Fluorine-Free Alternatives as Solutions, https://ipen.org/documents/global-pfas-problem-fluorine-free-alternatives-solutions

responses by manufacturers, users and authorities, are captured under Section 3. The list of specific foam products identified in the consultation responses (see Appendix 6) has been used to further prioritise and inform the shortlist of products considered for more in-depth analysis. All respondents to the consultation who provided information on the availability of alternative foam products reported that the foams are manufactured and used in the EU. Therefore, no information on relative or absolute amounts of foam derived by importing from outside the EU was available. A small number of manufacturers and users reported the volumes of some specific products produced, sold, or purchased in the EU, as well as the approximate value of these sales/purchases. It is not possible to comment on any broad observations from these small number of responses. These results have been used to supplement other information gathered (e.g. literature and the market analysis) to inform the more in-depth analysis;

- A small number of users indicated that the trend in their demand for foams has remained stable over the past 10 years, while one user (in the oil/gas/chemicals sector) noted that they expect an increase in demand as they switch further in favour of alternatives. Again, it is difficult to draw conclusions from a relatively small number of responses;
- In terms of the technical feasibility of alternatives, the responses received varied considerably for different individual foams, in terms of their perceived overall performance, and the compliance standards used to test their performance. The results obtained for the specific individual foam products have been be used to supplement the information already gathered in Section 3 (Substance ID);
- In terms of differences in volumes needed between alternatives and PFAS-containing foams, most responses suggested that there is not a difference between 'traditional' and 'alternative' foams. However, one user in the oil/petrochemicals sector suggests that the alternative foams need 30-50% more volume for the same performance. Again, the volume of foam needed depends on a variety of interdependent parameters and it is therefore not possible to draw general conclusions on required volumes. A number of respondents identified and discussed perceived critical uses or applications of foams where alternatives are lacking and PFAS-containing foams cannot be replaced; and
- In terms of economic feasibility of alternatives, a small number of responses were received providing details of costs of the alternative foam products, and their required loading, but very limited data was received on costs of replacing equipment. Similarly, limited quantitative data was provided on the potential savings associated with switching to alternatives.

In conclusion, the stakeholder consultation questionnaire responses yielded useful information that complement the data already gathered as part previous tasks.

7.4 Preparation of example list of alternative fluorine-free products

Step 3 - Preparation of shortlist of alternatives

In order to undertake a more in-depth analysis for a selected number of alternative products, a list of the most common alternative fluorine-free products, that are widely used in the EU, has been generated. These provide a starting point which can be compared to the risk, performance and cost of PFAS-based products, as discussed in more detail under other tasks within this study and that of the Commission.

Alternative techniques could be changes in demand for flammable fuels which would reduce the need for AFFFs. Application of e.g. electric aircraft and phase out of hydrocarbon fuels for vehicles would reduce the needs for AFFFs, but are by the authors of this report not considered feasible alternative solutions in the short term.

The selection of fluorine-free products for further analysis has been based on the following criteria:

- **Use** - The use of the products has been reported by several stakeholders, ensuring that the products analysed are commonly used in the EU as alternatives for PFAS-containing foams;
- **Chemical group** - The products represent different chemical groups according to the grouping in Task 1 of the DG ENV study, i.e. hydrocarbons, detergents, siloxanes and proteins. Some products may contain a combination of substances from these groups;
- **Technical feasibility** - The products do actually represent alternatives/replacements for PFAS-containing foams, including in critical situations (with large fires). Technical feasibility also considers the combination of the foam concentrate, the application system and the application rate to establish whether the alternative is a viable replacement. Case studies of critical applications serve as a starting point for successful replacement of PFAS-containing foams with fluorine-free alternatives. Training foams have been excluded as they are already available and widely used for all applications. ;
- **Manufacturers** – The products originate from different manufacturers;
- **Availability** – The products are known to be on the market in the EU and are available without further R&D delays or costs; and
- **Complementarity** - The products cover jointly all major applications of PFAS-containing foams and can be used in different conditions.

For the October 2019 workshop, an initial shortlist with 30 products from 8 manufacturers was generated (Appendix 6). The initial shortlist was presented at the workshop, and participants were asked which were the most commonly used and viable.

On the basis of the workshop feedback, further review by the study team and responses from stakeholders, a list of products for further analysis was generated. This is shown in Table 7.1 along with a justification of why these specific products have been chosen.

For each of the manufacturers, one or two products in the product range has been selected for the more detailed assessment. The selection has been based on the available information on the feasibility of using the alternatives with particular emphasis on products demonstrated as viable alternatives to PFAS-containing foams in airports and the petrochemical sector. The information provided in Table 7.1 is supplemented with two representative case studies in section 7.6.

The remaining products on the shortlist presented at the workshop were from the manufacturers Auxquimia (EE-3 Newtonian Training foam, and Unipol-FF), Fomtec (the Enviro product range) and the 3F Company (Freedol SF). None of the companies have answered the questionnaire and only limited information on the feasibility has been obtained from the stakeholder consultation. These products were not included in the list, but this does not indicate that these products are considered less efficient alternatives to the PFAS-based foams, merely that less information on the feasibility of using these foams was available for the assessment. Seven substances have been selected in order to strike a balance between ensuring variety in coverage of alternatives and depth of analysis that is possible.

It is important to note that during the substance identification task of the Commission study, a group of potential alternative fluorine-free products, the **siloxane-based** alternatives, were identified. These have not been identified as being widely used and, furthermore, at the stakeholder workshop, concerns were raised by governmental stakeholders in relation to PBT and/or vBvP properties of some siloxanes. They have therefore not been selected from the more detailed analysis.

One **protein-based** product, PROFOAM 806G from the company Gepro has been mentioned to be in use during the stakeholder consultation. However, specific data on users, application or feasibility have not been provided by the stakeholder consultation and the manufacturer and products cannot be identified. Proteinbases foams are marketed by Profoam srl (PROVEX AR 6-6), Angus PFAS based foams (TF 3 and TF90 for training purposes) and Dr Stahmer (Foamousse® product range). No information on these products has been provided for the stakeholder consultation but one product from the Foamousse® product range has subsequently been added to the example list in the table below.

Table 7.1 Example list of products for further analysis

Product name	Manufacturer	Chemical group(s)	Current use sector of the product where PFAS-based products are currently used	Reason for shortlisting	Other marketed fluorine- free products from the manufacturer for hydrocarbon fires
Respondol ATF 3-6%	Angus fire	Hydrocarbons and detergents	Petrochemicals - processing, storage and transport of hydrocarbons and polar solvents	Applicable for all types of flammable liquid fires	JetFoam ICAO-C (aviation) JetFoam ICAO-b (aviation) Syndura (aviation, forestry)
Re-Healing Foam RF1 1%	Solberg	Hydrocarbons and detergents	Petrochemicals - offshore oil installations and onshore terminals and refineries	Widely used - detailed information on the feasibility of using the substances as alternatives for PFAS-based products in the petrochemical sector provided in Case 2	8 other products in the Re-Healing Foam RF product range
Re-Healing Foam RF3x6 ATC	Solberg	Hydrocarbons and detergents	Aviation	Widely used - detailed information on the feasibility of using the substances as alternatives for PFAS-based products in the aviation sector provided in Case 1	
Moussol FF 3x6	Dr. Sthamer	Hydrocarbons and detergents	Aviation Petrochemicals	Widely used in several major EU airports	A number of products in the Sthamex® product range (municipal fire services, aviation, training foams) Training foam N (training) vaPUREx® LV 1% F10 (extensive fires of non-polar liquids) vaPUREx® LV ICAO B 3% F-10 (aviation)
Foammousse 3% F-14	Dr. Sthamer	Protein	According to manufacturer: Petroleum industry and on oil tankers	Best available example of protein-based products	
Ecopol Premium	Bioex	Hydrocarbons and detergents	Aviation	Mentioned by manufacturer and other stakeholders, as applicable for hydrocarbon fires, all types of flammable polar solvent liquids and applicable for tank fire fighting	BIO FOR BIO FOAM 5 and 15 (storage facilities, marine) BIO T3 and BIO T6 (training foams) Ecopol F3 HC, Ecopol A

Product name	Manufacturer	Chemical group(s)	Current use sector of the product where PFAS-based products are currently used	Reason for shortlisting	Other marketed fluorine- free products from the manufacturer for hydrocarbon fires
Orchidex BlueFoam 3x3	Orchidee	Hydrocarbons and detergents	Aviation	Has according to stakeholder response substituted for AFFF for one of the biggest airports in Germany	Other products in the Orchidex Bluefoam product range

7.5 Properties of shortlisted products

Step 4 – Additional information gathering and assessment of shortlisted alternatives

Additional information on the technical and economic feasibility and availability of shortlisted products has been collected through both the earlier literature review step and further follow-up with stakeholders. The properties of the shortlisted products are listed in the following tables and are further used in the socio-economic impact analysis in Chapter 8.

The full chemicals composition of the products is in general not available. The following tables indicate the substances listed in the safety data sheets i.e. the constituents classified as hazardous. It should be noted that not all human health or environmental hazard endpoints (e.g. endocrine disrupting effects) have necessarily been assessed in detail for each component by the foam manufacturers. Therefore, it should be kept in mind that the conclusion on risks in the tables below are based on the information provided in the product safety data sheets and hence other hazards may become evident in the future. A comprehensive list of identified substances in alternatives is provided in Section 3.

Table 7.2 Respondol ATF 3-6%

Product name		**Respondol ATF 3-6%**
Manufacturer		Angus Fire
Chemical group		Hydrocarbons and detergents.
Chemical composition		Substances listed in safety data sheet: 1-dodecanol 1-tetradecanol propylene glycol monobutyl ether disodium isodecyl sulfosuccinate sulfuric acid, mono-C8-10-alkyl esters, sodium salts reaction mass of C-isodecyl and C-isoundecyl sulphonatosuccinate.
Proposed PFAS foam substitution (as specified by manufacturer)		Replacing traditional AFFF and FFFP foam concentrates as well as fluoroprotein foam.
Technical feasibility	Applications areas (as specified in technical specification)	Class B hydrocarbon fuels at 3% and polar solvent fuels at 6%. Class A fuels (as wetting agent). Used in high risk situations where hydrocarbons (such as oils, gasoline, diesel fuel, and aviation kerosene) are stored, processed, or transported and/or polar solvents (such as alcohols, ketones, esters, and ethers) are stored, processed, or transported.
	Compliance with international performance standards	EN 1568 Part 3 and 4; Highest approval rating on all fuels using all waters; 1A/1A – 1A/1A – 1A/1A. (see Appendix 5)

Product name		Respondol ATF 3-6%
	Examples of use experience and performance compared to PFAS-containing foams	Used within the petroleum industry. No further details available. Marketed for use in Power and Industry (other than petrochemical), municipal fire brigades and forestry
	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why	The product is not intended for the aviation sector for which the manufacturer markets other products (JetFoam and Syndura product ranges) The corresponding 3-3% product has passed Lastfire test in fresh water and sea water. Stakeholders have indicated that fires in very large tanks are still challenging
	Need for changes in equipment	In general no need for replacement of equipment, but adjustment and in some case change of components
Economic feasibility:	Unit price	No data
	Unit price as compared with PFAS-containing foam for same application	No data
	Relative volume required to achieve comparable/best possible performance	No data
	Storage, shelf-life	Max. continuous storage temperature 49 C° (no performance loss after thawing), min. 10 years.
	Frequency of foam replacement	Depending on application and difficult to compare with the PFAS-containing . Commonly, the foam is used continuously for training and system testing as well, thus not requiring replacement.
Availability:	Volume manufactured, sold and used in the EU	No data
	Production capacity in the EU	No data
Risks:	CMR properties	Substances in the product do not meet the CMR criteria
	Other potential human health concern	Hazard classification of some constituents: H315 - Causes skin irritation. H319 - Causes serious eye irritation. H302 - Harmful if swallowed No other health concern identified
	PBT or vPvB properties	The product does not meet the PBT or vPvB criteria.
	Other environmental risk concern	Hazard classification of some constituents: -dodecanol (EC No 203-982-0; CAS No 112-53-8): H400 - Very toxic to aquatic life -tetradecanol (EC No 204-000-3; CAS No 112-72-1): H410 - Very toxic to aquatic life with long-lasting effects -dodecanol (EC No 203-982-0; CAS No 112-53-8): H411 - Toxic to aquatic life with long-lasting effects Sodium laureth sulphate (EC No 500-234-8; CAS No 68891-38-3): H412 - Harmful to aquatic life with long lasting effects
	GreenScreen® level	Level bronze[1]. Level Bronze Screening Requirements are[2] 1. Each intentionally added chemical compound present above 0% by weight (>0 ppm) and each impurity present at or above 0.01% by weight (100 ppm) in the product is screened with GreenScreen List Translator™. 2. Each screened chemical compound in the Product Inventory has a GreenScreen List Translator TM score of LT-P1, LT-UNK, and/or NoGSLT. No LT-1 scores are permitted in certified products.

Product name		Respondol ATF 3-6%
		3. Product-level acute aquatic toxicity testing results in LC50 and/or EC50 values >10 mg/l for each of the following groups of organisms: fish, aquatic and invertebrates, and algae.
	Conclusion on risks	As the substances are not classified with CMR properties and do not meet the PBT/vPvB criteria, the overall risks are considered lower than the risks of PFAS-based products. Some constituents are classified toxic or very toxic to aquatic life, for one constituent with long-lasting effects.

References:
[1] https://www.greenscreenchemicals.org/certified/products
[2]
https://www.greenscreenchemicals.org/images/ee_images/uploads/resources/GSCFirefightingFoamStandardV1.0_FINAL.pdf?cachebuster:38

Table 7.3 Re-Healing Foam RF3x6 ATC

Product name		Re-Healing Foam RF3x6 ATC
Manufacturer		Solberg
Chemical group		Hydrocarbons and detergents
Chemical composition		Substances listed in safety data sheet: 2-(2-butoxyethoxy)ethanol starch sucrose 1-propanaminium, N-(3-aminopropyl)-2-hydroxy-N,N-dimethyl-3-sulfo-, N-coco acylderivs., hydroxides, innersalts
Proposed PFAS foam substitution (as specified by manufacturer)		Replacing traditional AFFF and FFFP foam concentrates as well as fluoroprotein foams
Technical feasibility	Applications areas (as specified in technical specification)	Class B hydrocarbon fuels at 3% and polar solvent fuels at 6% Class A fuels
	Equipment	Aspirating or non-aspirating devices
	Compliance with international performance standards	EN 1568 Part 3 and 4; levels not indicated ICAO Levels B and C (see Appendix 5)
	Examples of use experience and performance compared to PFAS-containing foams	Airport Fire Service, both airport rescue firefighting and training. Examples: Used at Copenhagen Airport. Fulfilling the need of an alcohol resistant foam. Also used by the Melbourne Metropolitan Fire Brigade (MFB) on class B fires; Based on MFB's experience, Solberg RF3x6 foam concentrate performs just as well as the previously used fluorinated AFFF concentrate (IPEN 2019).
	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why	None identified within aviation. Several stakeholders indicate that the performance standards required by the ICAO were developed for PFAS-based foams, are outdated and/or are not covering the multiple applications within the aviation sector. For this reason(s), several airports conducted internal testing schemes before implementation of PFAS-free foams.
	Need for changes in equipment	No identified. In the case of Copenhagen Airport, the investment in fire trucks was not strictly conditioned by the foam replacement, but the coincident introduction of new trucks and foam was seen as a cumulative benefit.
Economic feasibility:	Unit price	Appr. €5/l
	Unit price as compared with PFAS-containing foam for same application	Range from similar to +20%.

Product name		Re-Healing Foam RF3x6 ATC
	Relative volume required to achieve comparable/best possible performance	No difference or differences/larger volumes depending on application. In certain applications, a 6% foam (ICAO Level C) has been found to work better than a 3% mixture (ICAO Level B).
	Storage, shelf-life	1.7 to 49 C° (no quality loss after thawing), 20 years
	Frequency of foam replacement	Depending on application. Commonly, the foam is used continuously for training and system testing as well, thus not requiring replacement.
Availability:	Volume manufactured, sold and used in the EU	Produced in Norway and Spain
	Production capacity in the EU	No data
Risks:	CMR properties	Substances in the product do not meet the CMR criteria
	Other potential human health concern	Hazard classification of one constituent: H319 - Causes serious eye irritation.
	PBT or vPvB properties	According to SDS, due to insufficient data no statement can be made whether the components fulfil the criteria of PBT (vPvB criteria not addressed)
	Other environmental risk concern	Hazard classification of one constituent: 1-propanaminium, N-(3-aminopropyl)-2-hydroxy-N,N-dimethyl-3-sulfo-, N-coco acylderivs., hydroxides, innersalts (EC No 268-761-3; CAS No 68139-30-0): H411 - Toxic to aquatic life with long-lasting effects
	Conclusion on risks	Substances in the product do not meet the CMR criteria. No statement can be made on whether the components fulfil the PBT criteria. One constituent is toxic to aquatic life with long-lasting effects.

Table 7.4 Re-Healing Foam RF1 1%

Product name		Re-Healing Foam RF1 1%
Manufacturer		Solberg
Chemical group		Hydrocarbons and detergents
Chemical composition (according to SDS)		Substances listed in safety data sheet: d-glucopyranose, oligomers, decyl octyl glycosides sodium octyl sulphate sodium decyl sulphate alpha-sulfo-omega-hydroxy-poly(oxy-1,2-ethanediyl), C9-11 alkyl ethers, sodium salts 1-propanaminium, N-(3-aminopropyl)-2-hydroxy-N,N-dimethyl-3-sulfo-, N-coco acyl derivs., hydroxides, inner salt amides, coco, N-[3-(dimethylamino)propyl] 1-propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-,N-coco acyl derivs., hydroxides, inner salts amides, coco, N-[3-(dimethylamino)propyl], N-oxides sucrose 2-(2-butoxyethoxy)ethanolsulfuric acid, mono-C12-14-alkyl esters, compound with triethanolamin
Proposed PFAS foam substitution (as specified by manufacturer)		Replacing traditional AFFF and FFFP foam concentrates as well as fluoroprotein foams
Technical feasibility	Applications areas (as specified in technical specification)	Petrochemicals sector - offshore oil installations and onshore terminals and refineries Class B hydrocarbon fuels (not intended for polar solvent fuels) Class A fuels

Product name		Re-Healing Foam RF1 1%
	Compliance with international performance standards	EN 1568 Part 3 (see Appendix 5)
	Examples of use experience and performance compared to PFAS-containing foams	Used at offshore facilities in Norway. Partially implemented at onshore facilities as well
	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why	According to data sheet, the product is not intended for use on Class B polar solvents fuels. Diverging opinions among stakeholders: Specific applications related to large storage tanks in the petroleum industry (e.g. terminals and oil refineries) may require PFAS-based foams. However, the use of PFAS-free foams has also been assessed as safe for sub-ground large storage tanks. One stakeholder noted that testing and qualification of non-PFAS foams and obtaining the necessary military approvals for use in all vessels / fire-fighting systems will take many years, and the associated costs will be very high.
	Need for changes in equipment	The experience with the case from the Norwegian offshore sector (Equinor, case 2) is that at a few facilities, adjustment of equipment was necessary, but usually, the same equipment was used and additional costs for new equipment were not necessary. Furthermore, substitution was done in relation to scheduled maintenance stops, turnarounds or during upgrades, thus not imposing further additional costs to the company.
Economic feasibility:	Unit price	Approx. €5.0-5.5/l
	Unit price as compared with PFAS-containing foam for same application	Case 2 indicates approx. 30% more expensive than PFAS products
	Relative volume required to achieve comparable/best possible performance	Same volumes, no difference to PFAS foams
	Storage, shelf-life	-10 to 50 C° (no quality loss after thawing), 20 years
	Frequency of foam replacement	Depending on application. Commonly, the foam is used continuously for training and system testing as well, thus not requiring replacement.
Availability:	Volume manufactured, sold and used in the EU	Available in EU (tonnage not known)
	Production capacity in the EU	Manufactured in the EU: no data Sold in the EU: no data Used in the EU: no data
Risks:	CMR properties	Substances in the product do not meet the CMR criteria
	Other potential human health concern	Hazard classification of product: H315 - Causes skin irritation H318 - Causes serious eye damage. Hazard classification of some constituents: H302 - Harmful if swallowed H314 - Causes severe skin burns and eye damage
	PBT of vPvB properties	According to SDS, due to insufficient data no statement can be made whether the components fulfil the criteria of PBT and vPvB
	Other environmental risk concern	Hazard classification of one constituent: amides, coco, N-[3-(dimethylamino)propyl] (-) (EC No 268-771-8; CAS No 68140-01-2): OH400: Very toxic to aquatic life
	Conclusion on risks	The constituents of the product do not meet the CMR criteria. Due to insufficient data no statement can be made on whether the constituents fulfil the PBT and vPvB criteria. One constituent is very toxic to aquatic life.

Table 7.5 Moussol FF 3x6 (F-15)

Product name		**Moussol FF 3x6 (F-15)**
Manufacturer		Dr. Sthamer
Chemical group		Hydrocarbons and detergents
Chemical composition		Substances listed in safety data sheet: 1,2-ethandiol 2-(2-butoxyethoxy)ethanol triethanolammonium-laurylsulfate alkylamidobetaine
Proposed PFAS foam substitution (as specified by manufacturer)		Replacing alcohol-resistant AFFF.
Technical feasibility	Applications areas (as specified in technical specification)	Polar (water-miscible) and non-polar hydrocarbons as well as mixtures of the two (class A and B fires). Can be used as a low, medium and high expansion foam.
	Compliance with international performance standards	DIN EN 1568: Part 3 (Heptane): IIIB/IIID, Part 1: Medium ex. - Part 2: High ex. ICAO Low expansion foam - Level B DIN EN 3 21A (see Appendix 5)
	Examples of use experience and performance compared to PFAS-containing foams	Used within aviation, for example in Sweden, by Swedavia, and in the UK at Heathrow Airport. Swedavia is a state-owned company that owns, operates and develops Sweden's national basic infrastructure of airports. The product is used at all Swedish airports as well as for all aircraft applications at Heathrow airport including training. The foam has been tested and fulfils the requirements of International Civil Aviation Organization, European Aviation Safety Agency and the International association of fire and rescue service.
	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why	One stakeholder states that the foam must be used aspirated, which reduces throw length. This may result in accessibility problems, for examples for large tanks. Other critical applications may be tank pit scenarios and large puddle fires (>400 m^2).
	Need for changes in equipment	No data
Economic feasibility:	Unit price	No data
	Unit price as compared with PFAS-containing foam for same application	Product costs about half of the corresponding PFAS-based foam, but approx. double volume is needed, thus the costs are the same. More storage capacity is required though.
	Relative volume required to achieve comparable/best possible performance	Depending on application.
	Storage, shelf-life	-5 to 50°C (without quality loss below the specified frost resistance limit) Shelf life of >10 years, if stored according to recommendations
	Frequency of foam replacement	10 years
Availability:	Volume manufactured, sold and used in the EU	Produced in Germany, data on volume considered confidential by manufacturer
	Production capacity in the EU	No data
Risks:	CMR properties	Substances not classified with CMR properties
	Other potential human health concern	Hazard classification of product; H319 - Causes serious eye irritation. Hazard classification of one constituent: H302 - Harmful if swallowed H319 - Causes serious eye irritation.

Product name		Moussol FF 3x6 (F-15)
		H373 - May cause damage to kidneys through prolonged or repeated exposure if swallowed.
	PBT of vPvB properties	Substances in the product do not meet the PBT/vPvB criteria
	Other environmental risk concern	Hazard classification of one constituent: Triethanolammonium laurylsulfate (EC No 288-134-8; CAS No 85665-45-8): 412: Harmful to aquatic life with long-lasting effects C
	Conclusion on risks	As the constituents are not classified with CMR properties and do not meet the PBT/vPvB criteria, the overall risks are considered lower than the risks of PFAS-based products. One constituent is classified harmful to aquatic life with long-lasting effects.

Table 7.6 FOAMOUSSE® 3% F-15

Product name		FOAMOUSSE® 3% F-15
Manufacturer		Dr. Sthamer
Chemical group		Protein
Chemical composition		Is a low expansion protein foaming agent based on natural re-growing protein carriers, foam stabilisers and antifreezing compounds. Substances listed in safety data sheet: iron-(ii)-sulfate-7-hydrate ammoniumchloride
Proposed PFAS foam substitution (as specified by manufacturer)		Not specified
Technical feasibility	Applications areas	Typically used in non-polar hydrocarbon fires in the petroleum industry and on oil tankers In particular used in the marine sector. Has the advantage that the product is compatible with black steel and does not require equipment made from stainless steel or plastics (same for other protein-based products). Has been in use for many years and not developed as an alternative to the PFAS-containing foams. Designed for the use with all mobile and stationary low expansion foam equipment and systems for fighting fires of class A + B.
	Compliance with international performance standards	EN 1568 part 3 (heptane)
	Examples of use experience and performance compared to PFAS-containing foams	Mainly used in the marine sector
	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why	Only applicable for smaller fires and not applicable for e.g. the aviation sector and other sectors with higher requirements.
	Need for changes in equipment	No data
Economic feasibility:	Unit price	Not specified but the price is indicated as relatively low
	Unit price as compared with PFAS-containing foam for same application	Lower
	Relative volume required to achieve comparable/best possible performance	No data

Product name		FOAMOUSSE® 3% F-15
	Storage, shelf-life	A shelf life of >10 years, if stored according to the manufacturer's recommendations
	Frequency of foam replacement	No data
Availability:	Volume manufactured, sold and used in the EU	Produced in Germany, data on volume considered confidential by manufacturer
	Production capacity in the EU	No data
Risks:	CMR properties	Substances in the product do not meet the PBT/vPvB criteria
	Other potential human health concern	Hazard classification of some constituents: H302 - Harmful if swallowed H315 - Causes skin irritation H319 - Causes serious eye irritation
	PBT of vPvB properties	Substances do not meet the PBT/vPvB criteria of REACH
	Other environmental risk concern	None of the constituents have hazard classification for environmental effects
	Conclusion on risks	As the constituents are not classified with CMR properties and do not meet the PBT/vPvB criteria, the overall risks are considered lower than the risks of PFAS-based products. The product is particularly applied in the marine sector, where volumes used for training are discharged directly to the sea. None of the constituents have hazard classification for environmental effects.

Table 7.7 Ecopol Premium

Product name		Ecopol Premium
Manufacturer		BIOex SAS
Chemical group		Hydrocarbons and detergents
Chemical composition		Substances listed in safety data sheet: 2-(2-butoxyethoxy)ethanol Ethandiol Alkyl Sulfate Sodium octyl sulphate
Proposed PFAS foam substitution (as specified by manufacturer)		Equivalent to AFFF (certified 1A / 1A - EN 1568-3) and burn back resistance equal to fluoroprotein foams ECOPOL PREMIUM can substitute for FILMOPOL range from same company (other products from the company can substitute for other PFAS-based products)
Technical feasibility	Applications areas (as specified in technical specification)	Industrial fires: landfills, plastics, tyres, etc. Hydrocarbon fires: fuel, diesel oil, petrol, kerosene, etc. Polar solvent fires: alcohols, ketones, ethers, etc. Urban fires: waste bins, furniture, textiles, etc. Effective at Low, Medium and High Expansion
	Compliance with international performance standards	EN 1568 - 1: Conforms EN 1568 - 2: Conforms EN 1568 - 3: 1A / 1A (highest level) EN 1568 - 4: 1A / 1A (highest level) Oil industry: LASTFIRE Forest fire standards: CEREN Certificate Certification in progress : UL 162 / GESIP (see Appendix 5)
	Examples of use experience and performance compared to PFAS-containing foams	According to producer's datasheet is used in the oil and chemical industry, pharmaceutical industry, aviation, marine, and fire and rescue service.

Product name		Ecopol Premium
		Used in industrial uses for tank fire fighting. Further details not available.
	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why	Diverging opinions among stakeholders. One stakeholder notes that the product is not technically feasible for large scale tank fire fighting, high-hazard industry manufacturing, oil tankers fire suppression systems, large spillage of flammable liquids
	Need for changes in equipment	One stakeholder indicated that re-building of firefighting or fire protection systems would be very costly, but no detailed information is provided.
Economic feasibility:	Unit price	3.5 EUR/l
	Unit price as compared with PFAS-containing foam for same application	Approximately the same effective price
	Relative volume required to achieve comparable/best possible performance	One stakeholder responds 30 – 50% more volume needed.
	Storage, shelf-life	-30°C to 60°C, 10 years warranty
	Frequency of foam replacement	Depending on application. Commonly, the foam is used continuously for training and system testing as well, thus not requiring replacement.
Availability:	Volume manufactured, sold and used in the EU	Production in EU: 700,000 l/year; Sale in EU: 500,000 l/year
	Production capacity in the EU	No data
Risks:	CMR properties	Substances not classified for CMR properties
	Other potential human health concern	Hazard classification of one constituent: H318 - Causes serious eye damage.
	PBT of vPvB properties	No PBT or vPvB properties identified
	Other environmental risk concern	None of the constituents are classified with regard the environmental hazards.
	GreenScreen level	Level Bronze. Level Bronze Screening Requirements are 1. Each intentionally added chemical compound present above 0% by weight (>0 ppm) and each impurity present at or above 0.01% by weight (100 ppm) in the product is screened with GreenScreen List Translator™. 2. Each screened chemical compound in the Product Inventory has a GreenScreen List Translator TM score of LT-P1, LT-UNK, and/or NoGSLT. No LT-1 scores are permitted in certified products. 3. Product-level acute aquatic toxicity testing results in LC50 and/or EC50 values >10 mg/l for each of the following groups of organisms: fish, aquatic and invertebrates, and algae.
	Conclusion on risks	As the constituents are not classified with CMR properties and it does not meet the PBT/vPvB criteria, the overall risks are considered lower than the risks of PFAS-based products

Table 7.8 Orchidex BlueFoam 3x3

Product name	Orchidex BlueFoam 3x3
Manufacturer	Orchidee
Chemical group	Hydrocarbons and detergents
Chemical composition	Substances listed in safety data sheet: L2-(2-butoxyethoxy)ethanol, diethylene glycol monobutyl ether ethanediol, ethylene glycol

Product name		Orchidex BlueFoam 3x3
		alcohols, C10-16,ethoxylated, sulfates,ammonium salts D-glucopyranose oligomeric C10-16-alkyl glycosides ammonium lauryl sulfate alcohols, C10-16,ethoxylated dodecanol -1
Proposed PFAS foam substitution (as specified by supplier)		Products can be seen as 1:1 replacement on Sthamex AFFF and Moussol Products or other AR or usual AFFF products. Appropriate foaming is needed – as for all PFAS-free products - which can usually be realised with the equipment to hand. On systems the nozzles/sprinklers needs changing. Main strength on non-polar liquids.
Technical feasibility	Applications areas (as specified by supplier)	Aviation, petrochemical sector For all uses till tanks > 15 m diameter.
	Compliance with international performance standards	EN 1568 - 3: 1B EN 1568 - 4: 1A / 2B Oil industry Lastfire (Heptane), ICAO Level B (see Appendix 5)
	Examples of use experience and performance compared to PFAS-containing foams	Indicated by supplier that one of the biggest airports in Germany has changed to the product. After tests with their trucks to test the capabilities for their dosing-system, the airport has decided to change all trucks to PFAS-free and has now started a project to change also all systems.
	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why	Indicated by supplier that fires in substances like isopentane (with low boiling points of 28°C) are difficult and PFAS-containing foams may have an advantage. This could according to the supplier be overcome with a higher application-rate and/or more technical changes to technique and equipment. In the view of supplier and experience from dozens of tests done in the past 10 or more years it's generally possible to change 99.9 % of all current scenarios to PFAS-free.
	Need for changes in equipment	Indicated by supplier as normally none. Some information from airport in Germany that changes of trucks may be needed, but not indicated it this concerns adjustment or actual changes in equipment.
Economic feasibility:	Unit price	Depending on concentration, the price in sales is in the range €2.5 – 6.0/l
	Unit price as compared with PFAS-containing foam for same application	No data
	Relative volume required to achieve comparable/best possible performance	According to supplier, if there might be a gap, it's in between 5-10 % in the extinguishing-time for PFAS-containing products in regard to mainly unpolar and secondly polar liquids. In tests, nearly 1:1 results were found, but this is strongly depending on the fuels and additives.
	Storage, shelf-life	No data
	Frequency of foam replacement	5-15 years
Availability:	Volume manufactured, sold and used in the EU	Stakeholder (not the manufacturer) estimates volume sold in the EU at 800 t/year
	Production capacity in the EU	No data
Risks:	CMR properties	Substances not classified with CMR properties
	Other potential human health concern	Hazard classification of several constituents: H302 - Harmful if swallowed H318 - Causes serious eye damage H319 - Causes serious eye irritation H315 - Causes skin irritation
	PBT of vPvB properties	Product has not been tested according to SDS

Product name		Orchidex BlueFoam 3x3
	Other environmental risk concern	Hazard classification of one constituent: Ammonium lauryl sulfate (EC No 218-793-9; CAS No 2235-54-3): H412 - Harmful to aquatic life with long lasting effects.
	Conclusion on risks	None of the constituents are classified with CMR properties. Due to lack of information it cannot be concluded if the constituents fulfil the PBT and vPvB criteria. One constituent is harmful to aquatic life with long lasting effects.

7.6 Representative case studies where fluorine-free alternatives are already in use in the EU

Step 5 - Assessment of illustrative cases

An important issue in identifying the feasibility of alternatives is the consideration of the process that is involved in adopting the alternative, including systems that need to be changed and considerations such as additional training of users. Substitution examples from companies that are already using alternatives therefore act as a key starting point or proof of principle that a transition is (or is not) possible and the main costs and benefits from real world examples. In order to better understand the options and challenges of replacing PFAS-containing AFFFs, two cases where PFAS-containing AFFFs have been successfully replaced are described in more detail in the following case study examples.

Case 1 Aviation sector - Copenhagen Airport in Denmark[94]

Foam used

In general, the majority of firefighting foam is used for testing and training at airports. Only a very small percentage is used operationally for emergency response at live events. At Copenhagen airport, the same fluorine-free foam (Solberg Re-healing foam RF3x6 ATC fluorine-free foam) is used for training and emergency response.

Timeline in the shift from PFAS foams to fluorine free-foams

- In 2003, the airport recognised PFAS in the run-off firewater from the airport's training area and its burn pit. This resulted in restrictions on use of PFAS-containing AFFF and later, in 2006, all training with PFAS foams stopped;
- In 2008, testing with fluorine-free foams was started. Re-Healing foams from Solberg were identified as suitable alternatives; and
- In 2009, the airport conducted additional tests required by the ICAO ARRF working group. All tests (ICAO foam test and test according to the US Mil-Spec protocol, including the NFPA 403), were passed by the fluorine-free foam carrying airport crash tenders. The results from the UK CAA/ICAO tests also showed that CAFS (Compressed Air Foam System; application of foam

[94] Case description is based on the following sources:
IPEN position paper 2018 (https://ipen.org/sites/default/files/documents/IPEN_F3_Position_Paper_POPRC-14_12September2018d.pdf)
IPEN position paper 2019 (https://ipen.org/sites/default/files/documents/the_global_pfas_problem-v1_5_final_18_april.pdf)
Kim T. Olsen, 2017, Crashtender med skumkanoner (https://beros.dk/skum/Kim_Thorbjoern_Olsen_CPH.pdf)
Personal communication with Kim T. Olsen, 2019

with non-aspirating turret)[95] were about 40% more efficient in fire extinction compared to aspirated foams. CAFS with PFAS and PFAS-free foams were both shown to be efficient. The PFAS-free foam was implemented jointly with three new airport crash tenders (specialised firefighting trucks designed for use in aircraft rescue and firefighting at aerodromes) with CAFS on all low-pressure outlets.

Challenges

- Along with the implementation of the new firefighting trucks, the training of the firefighters with the new equipment and foams was a crucial issue and initial testing and training caused additional costs (exact cost estimates are unknown). Also, the different viscosity of the PFAS-free foam caused some initial challenges, which were later solved by the adjustment of equipment; and
- Some of the old trucks continued to be in use and, even though the tanks were cleaned thoroughly, a contamination of the PFAS-free foam with PFAS occurred initially.

Costs of replacement

- Upon implementation of the new fluorine-free alternative, testing and training required ~5,000 litres foam/year. However, with some modifications to the equipment and training, the volume has now been reduced to 3,000 litres foam/year. Optimal efficiency was found at a 6% foam concentration (ICAO Level C) instead of 3% (ICAO Level B), thus larger foam volumes may still be used in certain situations;
- Costs incurred in the replacement comprised mainly costs for destruction of PFAS-containing foams and additional training and testing. More specific cost estimates were not available in this case. However, it should be noted that the foam supplier also had an interest in supporting the implementation of the PFAS-free foam and carried out some of the foam testing and covered the additional costs; and
- The investment in new airport crash tenders (specialised fire engines designed for use in aircraft rescue and firefighting) was not strictly linked to the foam replacement, but the coincident introduction of new trucks and foam was seen as having a cumulative benefit.

Benefits

Copenhagen Airport is still working on the remediation of previous pollution from PFAS foams. In 2014, works on clean-up, containment and reconstruction of the fire training area were started and required an initial investment of more than €15 million. Currently, the maintenance of the drainage system around the fire training ground costs more than €1.5 million per year and this expenditure is expected to continue for at least the next 80 years.

The biggest benefit of switching to a fluorine-free alternative foam is that rainwater and firewater runoff can be discharged though the normal sewer system to the municipality's waste water treatment, thus avoiding long-term clean-up issues and remediation costs in the future.

[95] The difference between aspirating and non-aspirating equipment is that the aspirating device mixes air in the foam/water solution within the nozzle or foam maker, whereas non-aspirating devices do not. Typical examples of non-aspirating devices are water/fog nozzles, water spray heads and conventional sprinkler heads (Ansul Technical bulletin no. 55, https://www.ansul.com/en/us/DocMedia/F-83115.pdf).

Figure 7.1 Training at Copenhagen airport with crash tender. Picture courtesy of Kim T. Olsen, Copenhagen Airports A/S. (https://beros.dk/skum/Kim_Thorbjoern_Olsen_CPH.pdf).

Case 2 Petrochemical sector - Offshore production in Norway[96]

Foams used

Equinor, representing 80% of all production on the Norwegian Continental Shelf and equivalent to 50% of total production for the North Sea, have managed to substitute PFAS-containing foams with PFAS-free foams at almost all installations. The substitution is close to completion for ~40 offshore installations and is ongoing for five onshore facilities (terminals and an oil refinery). Fire-fighting foams at offshore installations are used for multiple applications including training, system testing and emergency response of live events.

At most facilities, Re-healing RF1, 1% foam from Solberg is used, while some older facilities use Re-healing RF1 3% foam. For a few installations (where there is risk of methanol fire), alcohol resistant foam was used. The 1% and 3% foam products are used for petroleum fires and were chosen because they are regarded as a drop-in replacement for fluorinated AFFF. For methanol fires specifically, Solberg Re-Healing Foam RF3x6 ATC (alcohol resistant foam) is used.

Basically, all foam is used for training and systems testing as emergency responses are seldom (have not occurred since the implementation of the substitution). Environmental discharges may also occur due to accidental spills.

The crude oil and products are stored in caverns i.e. underground storage tanks. The typical size is 50,000 – 280,000 m^3 for crude oils and 10,000 – 50,000 m^3 for products. The caverns are filled up with fluids to prevent them from catching fire.

[96] Case description based on the following sources:
IPEN position paper 2019 (https://ipen.org/sites/default/files/documents/the_global_pfas_problem-v1_5_final_18_april.pdf)
Personal communication with Lars Ystanes, Equinor, 2019

Timeline in the shift from PFAS foams to fluorine free-foams

- In 2010-2012, development and testing of a 1% fluorine-free firefighting foam was carried out as a collaborative project between Solberg Scandinavian and Equinor (named Statoil at that time). The driver for the replacement was concern of the environmental consequences of PFAS-containing firefighting foam released to the sea;
- In December 2012, the Re-healing RF1, 1% foam (RF1) was first used successfully on the offshore installation Kvitebjørn;
- In 2013, the RF1 foam was technologically approved for use by Statoil after an approval and verification process;
- In 2014, approval for starting the multi-use transition project was obtained, with the aim of implementing the new foams at all Norwegian operated installations with 1% foam systems;
- By September 2016, 30 of 31 Equinor assets had successfully implemented use of RF1 foam; and
- In 2018, Solberg launched a modified 1% RF1, with lower viscosity at low temperatures and with a yellow environmental classification (compared to red classification for RF1)[97] called RF1-AG. This product went into operational use in 2018 on all new offshore installations.

Challenges

During the substitution implementation, several technical issues occurred which had to be resolved using additional testing by Equinor:

- During full-scale testing with RF1, a break-down of the foam proportioner occurred which was initially linked to corrosion related to the use of the RF1 foam. Further investigation identified another reason for the break-down and it was concluded that RF1 had no influence on the foam proportioners;
- RF1 has a higher density and viscosity compared to the previously used AFFF. Higher density may be a problem for installations with substandard foam pumps. However, most Equinor installations were able to handle the increased viscosity and density with only minor system adjustments. At one installation, the pumps were not able to handle RF1 and the solution for this installation is still under evaluation; and
- Initial uncertainties related to the temperature tolerance of the foam have been removed. The products currently used have a freezing tolerance down to -19°C and acceptable low viscosity at ambient temperature.

Costs of replacement

For Equinor, the total costs of substitution of PFAS-containing foams at about 40 offshore installations and five onshore facilities has been estimated to be approximately €7 million. This estimate does not include costs related to R&D, and regulatory approval costs, which were undertaken in this case by the foam supplier (Solberg). At a few facilities, adjustment of equipment was necessary, but usually, the same equipment was used and new equipment (and associated cots) was not necessary. These total headline costs can be broken down further to include the following:

[97] Environmental colour marking system in Denmark and Norway of The Harmonised Offshore Chemical Notification Format under the OSPAR Convention 1992 indicating substances that should be considered candidates for substitution. "Red" substances may only be used in limited amounts and shall be substituted.

- The cost for support in the multi-use phase has been estimated at 2,500 working hours in the period from August 2013 to September 2016, corresponding to a total cost of approx. NOK 3.5 million (approx. €360,000). This included activities such as planning of implementation together with the supplier, preparation of information letters, support team, follow up on technical issues, etc;
- The cost related to replacement of foam in storage ranges from €50,000 to €500,000 for the biggest oil installations, corresponding to tank storages of 20 – 120 m^3. In total, approximately 1,100 m^3 of foam was replaced over a 3 year period, resulting in a rough cost estimate of 1,100,000 litre * €5 /litre = €5.5 million. Substitution has always been done in relation to scheduled maintenance stops, turnarounds or during establishing new equipment, thus not imposing further additional costs to Equinor. Note that replacement costs listed here are not due to a higher price of alternative, but due to the costs of replacing the PFAS-based foams in storage (costs of alternatives as compared to the PFAS-based foams);
- Additionally, the cost related to destruction/incineration of old the PFAS-based foam contributed a further approx. €1 million to the transition costs (~1,000,000 litre * €1 /litre); and
- Costs of decontamination of equipment were not significant and no fire-fighting equipment or storage tanks were replaced as part of the decontamination process. The storage tanks were drained empty to >99% and the PFAS-based foams handled as waste (destruction/incineration as indicated above). Washing water containing low levels of PFAS was discharged to the sea or waste water treatment plants. Compared to continuous use of PFAS, it was considered that the small discharges of washing water were insignificant.

Costs of alternatives

The costs of the new foams as compared the PFAS-based foams used before varied between +5% to +30%, depending on foam type/application. For the majority of the foams, the costs increased by +30% and the overall costs increase was slightly below +30%.

Benefits

- At onshore installations, PFAS foams have either been released during operations at the harbour or collected as hazardous waste water at the process plants. The disposal of hazardous waste water, consisting of appr. 1% foam and 99% water meant a significant cost item before the substitution. Waste water containing fluorine-free foams is treated at the biological waste water treatment plants of the onshore installations;
- Before the substitution, PFAS-containing AFFF were always discharged to the sea during training and system test at Equinor's offshore installations. The use of PFAS-free foams now means a significantly reduced environmental impact. The annual discharge of PFAS-based foams to the sea was reduced from 3-4 tonnes to (almost) zero;
- In 2014, Norwegian authorities required standard environmental documentation for all firefighting foam used in high volumes. Since Equinor have been successful in transitioning to PFAS-free foams, there is now a general pressure driving the Norwegian market towards the use of PFAS-free foams; and
- Equinor recognise the substitution as a good investment to be in position for future regulatory changes, but they also see value in reducing their chemical footprint and strengthening their market position as substitution leaders.

Figure 7.2 Firefighting training with foams at offshore platforms in Norway (picture courtesy of Lars Ystanes, Equinor)

7.7 Overall analysis of alternatives

Step 6 – Final summary

This section of the report draws together all of the information gathered under the previous tasks to produce an overall assessment of the technical feasibility, economic feasibility, and availability of alternatives to PFAS-containing fire-fighting foams. A summary for the seven evaluated alternative substances is in Table 7.9. Furthermore, reference is made to the two case stories from the aviation and petrochemicals sector, above. The seven products are selected from a list of more than 30 products marketed as alternatives to AFFFs, but are considered to be representative of the products on the market for the most sensitive uses of AFFFs for liquid hydrocarbon fires and of products that are in actual use (rather than others which may be marketed but actual use is unknown).

Technical feasibility

Aviation

Alternatives have successfully replaced the PFAS-containing foams in a number of airports. Based on the stakeholder consultation, three different products from three manufacturers have been reported to have replaced applications of AFFF in airports in Denmark (Copenhagen, Re-healing foam RF3x6 ATC), Germany ("one of the biggest airports", Orchidex BlueFoam 3x3, Sweden (Arlanda and other airports, Moussol 3/6-FF), and the UK (Heathrow, Moussol FF 3x6). The alternatives are used for all applications. According to the IPEN report "Fluorine-free firefighting foams (3F) viable alternatives to fluorinated aqueous film-forming foams", all of the 27 major Australian hub airports have transitioned to fluorine-free firefighting (F3) foams, as have the following major hub airports: Dubai, Dortmund, Stuttgart, London Heathrow, and Manchester, Copenhagen, and Auckland[98].

[98] Fluorine-free firefighting foams (3F) viable alternatives to fluorinated aqueous film-forming foams (AFFF), IPEN Stockholm Convention POPRC-14, Rome, September 2018

A case story from Copenhagen Airport demonstrates that some testing, modification of equipment and training has been required. The entire transition period was 6 years. Investment in new fire trucks took place at the same time, but this was not directly required due to the foam replacement.

It has been indicated by stakeholders that some airports voiced concerns over efficacy and changes of equipment, but no specific information has been obtained. The same certification tests apply for all airports in Europe and the successful transition in several airports indicates that it should be possible for others. Some alternatives comply with the highest ratings of N 1568,1A/1A for both Part 3 and 4. One stakeholder noted that high ambient temperatures can influence the performance of foams as demonstrated in an incident in Dubai. However, as mentioned above all 27 major Australian hub airports have transitioned to fluorine-free firefighting (F3) foam indicating that PFAS-free foams are also being applied at high ambient temperatures. One stakeholder (a supplier of AFFF and alternatives) with experience in transition in a German airport states that that experience from a large number of tests done in the past 10 or so years indicates it is possible to change 99.9 % of all current scenarios to PFAS-free products.

Upstream petrochemical sector

Equinor, the largest operator on the Norwegian continental shelf, has successfully replaced AFFF in about 40 offshore installations and five onshore facilities. At a few facilities, adjustment of equipment was necessary, but usually the same equipment was used and new equipment was not necessary.

At one installation, the pumps were not able to handle the alternative. The company had some challenges with the density and viscosity of the alternative foams initially used compared to the traditionally used AFFF, e.g. by lower ambient temperatures. This was solved by modifications of the alternative product. The shift took approximately eight years from the first tests to when the modified alternative was introduced on all installations.

Municipal fire brigades and forestry

PFAS-free alternatives are readily available for these areas and, as shown in Task 2, account for more than 60% of the total market. No data on costs of substitution specifically for these application areas have been provided in the stakeholder consultation or identified in the literature.

Marine applications

A wide range of PFAS-free foams are marketed for marine applications and it has not been indicated by any stakeholders that there might be particular challenges in changing to PFAS-free foams apart from the general need for adjustment and testing of equipment. One of the example products is a low expansion protein-based foam which is typically used in non-polar hydrocarbon fires in the petroleum industry and on oil tankers. It has the advantage that the product is compatible with black steel and does not require equipment made from stainless steel or plastics (and the same is the case for other protein-based products). It is designed for use with all mobile and stationary low expansion foam equipment and systems for fighting fires of classes A and B.

Military applications

Alternatives are less well established in the military sector, but it has been indicated by stakeholders that alternatives are considered to be feasible, although not many have yet been certified or implemented by users. The military applications are similar to those seen in airports and municipal fire brigades and the foams used are, after the necessary testing and adjustment of equipment, considered to be useful for military applications as well. As an example, the IPEN publication on "Fluorine-free firefighting foams (3F) viable alternatives to fluorinated aqueous film-forming foams (AFFF)" states that the Danish and Norwegian armed forces have moved to PFAS-free foams. The specific foams used have not been identified, but these are thought to be foams from major producers. As mentioned before, one stakeholder noted that testing and certification of PFAS-free foams and obtaining the necessary military approvals for use in all vessels / fire-fighting systems will take many years, and the associated costs will be very high. However, this has not been confirmed by other stakeholders.

Petrochemical processing and large storage tank farms

Use areas where PFAS-free alternatives have not been fully tested, is in the downstream petrochemical sector (refineries and steam crackers) and large storage tank facilities. In particular, for large storage tank fires, combatting these fires requires foams capable of flowing on large burning liquid surfaces and sealing against hot metal surfaces to prevent reignition. The development of suitable test criteria for large storage tanks and fluorine-free foams is ongoing under the LASTFIRE project. Several of the shortlisted products in this report have been tested and reported to be in compliance with the LASTFIRE criteria. According to a presentation by Nigel Ramsden, LASTFIRE, at the stakeholder workshop on 24 September 2019, it has been shown that PFAS-free foams can provide equivalent performance to C6 foams and provide appropriate performance for hydrocarbon fires in a number of test conditions:

- When used with NFPA application rates for the following applications:
  - Tank fires ~15m+ diameter (no reason to doubt results can be extrapolated to >25m+):
    - Conventional pourer standard application rates;
    - Aspirating monitor[99]; and
    - "Non aspirating" monitor with appropriate foam characteristics.
  - Tank fires ~60m+ diameter No reason to doubt results can be extrapolated to >80m +) or bund fires:
    - Foam pourer.
- When used at lower rates than NFPA using CAF application:
  - Tank fires ~15m+ diameter (no reason to doubt results can be extrapolated to >25m+):
    - Monitor application.
  - Tank fires ~80m+ diameter (no reason to doubt results can be extrapolated to >100m +) or bund fires:
    - Foam pourer.

It is stated in the presentation that test results for some conditions are still missing and LASTFIRE is going to work on these issues: specifically, polar solvent tests – foam application from longer distances, other foams/combinations of foam/application methods, tactics for life safety situations and optimising properties.

As indicated above, it can be concluded that even in large tanks alternatives can be applied, but the safety margin may be lower than for the PFAS-based foams. According to stakeholders, the largest risks are associated with fires in large tanks of crude oil because of the higher risk of boil-over. One stakeholder mentioned that fires in large tanks of ~40m are however very rare in the EU and they could not identify any such fires in Europe in the last 10 years.

A recent study by the Fire Protection Research Foundation (USA) determined the fire extinguishment and burnback times for five fluorine-free foams (FFF) and one short chain C6 Aqueous Film Forming Foam formulation (AFFF) as a function of application rate and foam discharge density for a range of test

[99] Fire fighting monitors are a controllable high-capacity water jet used for manual or automatic fire fighting

parameters including foam quality/aspiration, fuel type, water type and fuel temperature[100]. In summary, the authors conclude that PFAS-free foams have come a long way but there is still a lot more to learn about their capabilities and limitations. Furthermore, they conclude: "*As of today, FFFs are not a "drop in" replacement for AFFF. However, some can be made to perform effectively as an AFFF alternative with proper testing and design (i.e., with higher application rates/densities).*"[100]

No specific cases with successful 100% transition in installations with large tanks have been identified. According to stakeholders some examples exist where PFAS-free foams are used for the majority of applications but PFAS-based foams are still stored for use in emergency situations with large tank fires. A reported challenge in petrochemical processing and storage tank farms is the presence of tanks with different liquids that may require different alternatives because one alternative cannot be used for all the liquids. One supplier indicated that in some instances in the petrochemical industry two different alternatives could be required whereas another manufacturer indicated that even more than two may be required if many different liquids are stored.

As reported elsewhere, in the chemical/petrochemical sector approximately 93% of the foam volume is used for training. Most of the manufacturers provide PFAS-free training foams that mimic the AFFF and which are used for training. One manufacturer indicated that the PFAS-free training foams were not used in live-fire training ("hot training") As indicated in Task 2, PFAS-free alternatives account for 19% of the volume used in the chemical/petrochemical sector, but a major part of this is likely to be for training purposes.

Availability

A large number of alternatives are available from at least eight manufacturers. Most of these manufacturers also manufacture AFFFs and the alternative product range is often designed to match the product range of AFFFs. As demonstrated with the successful transition in many airports, products from several manufacturers are applicable for replacing the AFFF for the same application. Only limited information on actual production volumes for the individual products has been available from manufacturers because this information is generally considered confidential. The PFAS-free alternatives currently represent 32% of the market and this share is growing.

Based on interviews with three manufacturers of fire-fighting foams in Europe, it can be concluded that there is currently overcapacity in Europe e.g. one of the manufacturers indicated they are running at 10-20% of their capacity. One manufacturer indicated that they have also extra capacity for emergency situations. All three manufacturers estimated that the necessary volumes of alternatives could be supplied within a short time (one to a few years). All EU manufacturers are also formulators and the alternative products are formulated from common bulk raw materials for cleaning and washing agents, food products, etc. and not specifically produced for the alternative firefighting foams. The manufacturers indicated that raw materials are available in sufficient quantities. According to the manufacturers and other information from stakeholders, the main challenge in the transition would not be to meet the demand for those alternatives already on the market, but to develop alternatives for application areas where replacement is still challenging.

Health and environmental risks

For the shortlisted products, none of the components included in the Safety Data Sheets are classified with CMR properties. For most of the products, the Safety Data Sheets indicate that the products or components do not meet the PBT/vPvB criteria of REACH. For two products, it is reported in the Safety Data Sheet that sufficient data are available for assessing whether the components fulfil the PBT and vPvB criteria. None of the products, however, include substances demonstrated to be PBT or vPvB substances. The classification of the components of assessed alternatives indicates that other classified effects are "Causes skin irritation"

[100] Back, G.G., Farley, J.P. (2010). Evaluation of the fire protection effectiveness of fluorine free firefighting foams. Fire Protection Research Foundation.

(H302), "Causes serious eye irritation" (H319) and "Causes skin irritation" (H315). Many of the products do not include substances classified with environmental effects whereas others include one or more substances classified "Harmful to aquatic life with long lasting effect" (H412). It should be recognised, however, that not all human health or environmental hazard endpoints have necessarily been assessed in detail for each component by the foam manufacturers (for example, endocrine disrupting effects).

Economic feasibility

The available data indicates that the most significant one-off costs to transition to fluorine-free foams are associated with the following:

- **Replacement of foams in storage**. For Equinor, the costs of replacement of AFFFs was €5/l corresponding to €5.5 million;
- **Destruction of replaced AFFFs**. In addition to costs of about €1/l for the destruction of the replaced AFFFs, corresponding to a total of €1 million;
- **Decontamination of equipment**. The available cases do not indicate significant costs of decontamination of equipment. The equipment has typically been drained and decontaminated by cleaning with washing water which was discharged to waste water or surface water. However, the costs of cleaning of equipment will depend on the requirements as to the decontamination level and discharge of cleaning water. According to information from manufacturers, it may in some instances be less expensive to change part of the equipment than to clean it especially for stationary equipment. Stakeholders have reported, the requirements are different between Australia and New Zealand resulting in large differences in the costs of decontamination of equipment (specific data have not been obtained);
- **Management of the transition process.** Reported at €0.36 million for Equinor i.e. less than 10% of total transition costs;
- **R&D and regulatory approval costs.** These costs are usually covered by the manufacturers of foams and reflected in the price of the alternative foams;
- **Adjustment and replacement of equipment**. The available cases indicate that the costs of replacing equipment has been small in comparison to the cost elements listed above. According to stakeholders, extra storage capacity is not always required; and
- **Training in the use of new products.** The available cases do not indicate additional training costs; these are covered by the costs of testing and adjustment of equipment.

Regarding the effective price of alternatives, three interviewed manufacturers of PFAS-based foams and alternatives consider that the effective price is more or less the same and within +/- 20%. In accordance with this, additional recurrent costs for alternatives used in the aviation sector, stakeholders have reported that the effective price of the alternatives (taking efficiency of alternative into account) is more or less the same as the price of the AFFF used before the transition. The case from the offshore sector reports extra costs varying between +5% and +30% depending on application with total extra costs slightly below +30% as compared with the AFFFs used before. This may reflect the more diverse scenarios in the off-shore petroleum sector.

The reported shelf lives of alternatives range from >10 years to 20 years. Shelf life of PFAS-based foams is reported to be typically between 10 years and 20 years (to a maximum of 30 years)[101]. In general, the shelf life of the alternatives does not seem to be shorter than the shelf life of PFAS-based foams and no extra costs, as a consequence of differences in shelf life, have been indicated by stakeholders.

[101] Proposal for a restriction: Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related substances https://echa.europa.eu/documents/10162/a22da803-0749-81d8-bc6d-ef551fc24e19

The main advantages of using alternatives in the aviation sector are that the rainwater and firewater runoff from training grounds can be discharged though the normal sewer system to the municipality's waste water treatment system, thus avoiding long-term clean-up issues and remediation costs in the future. The case from Copenhagen airport demonstrates that works on clean-up, containment and reconstruction of the fire training area were started and required an initial investment of more than €15 million, and currently, the maintenance of the drainage system around the fire training ground costs more than €1.5 million per year and this expenditure is expected to continue for at least the next 80 years.

At offshore installations, training foams are typically discharged directly to the sea and it is not considered feasible to avoid this discharge by collecting and treating the AFFF-containing firewater.

As indicated above, the costs of destruction of PFAS-based foams is about €1/litre (a more detailed description of destruction costs is provided in section 10.2). The costs of destruction of the PFAS-based foams is likely to be incurred in any case when the foams expire (exceed their shelf life). In the past the PFAS-based foams were also used for training which meant that stocks were used before they reached the end of their shelf life. According to information from stakeholders it is today common to store PFAS-based foams which have reached their shelf-life whilst waiting for a less expensive solution for disposal. In a scenario where PFAS-based foams are used for emergency situations and PFAS-free foams are used for training, a cost of about €1/litre for destruction of the PFAS-based foams by the end of their service life should be expected.

Table 7.9 Evaluation of potential alternatives by application area

Parameter		Questions	Airports	Off-shore facilities	Petrochemical industry and large tank farms	Municipal fire brigades	Marine applications
Technical feasibility		Can alternatives perform the same functions as the PFAS-based foams for same application	Training: Yes Actual fires: Yes	Training: Yes Actual fires: Yes	Most training scenarios: Yes Large-scale fires: Not demonstrated for some situations	Training: Yes Actual fires: Yes	Training: Yes Actual fires: Yes
		Will it require changes (in processes, equipment, storage facilities, training, etc.)?	Adjustment of equipment, tests, training required. In some instances there may be a need for new equipment and increased storage capacity				
Availability	Current and future availability Timeframe	Is it available in the required tonnage / amount in the EU / worldwide?	Yes	Yes	Yes for most training No - further tests of alternatives required for actual emergency situations in large tank farms and some other installations	Yes	Yes
		How fast could enterprises make the switch? What would be the downtime, if any?	Meeting market requirements not considered a challenge as transition is expected to take some years	Meeting market requirements not considered a challenge as transition is expected to take some years	No challenge for training foams Further development required for large tank farms	Meeting market requirements not considered a challenge as transition is expected to take some years	Meeting market requirements not considered a challenge as transition is expected to take some years

Parameter		Questions	Airports	Off-shore facilities	Petrochemical industry and large tank farms	Municipal fire brigades	Marine applications
Risks	Human health	Information on the hazards: properties causing the concern for the substance to be restricted / other properties.	None of the constituents of the alternatives meet the CMR criteria. Classification of constituents of alternatives does not point to any significant health concern. This assessment is based on hazard information identified in safety data sheets for relevant products. The safety data sheets include constituents with a hazard classification, and the conclusion that the alternatives do not meet the CMR criteria are considered robust for the foams evaluated in more detail. However, there was insufficient information to conclude whether the underlying test/endpoint data was equivalent for these substances and the alternative products compared to the PFAS-based products Some constituents are classified with hazard phrases such as harmful if swallowed and causes serious eye irritation and occupational exposure should be reduced by use of adequate protective equipment, but this would likely apply to any fire-fighting foam.				
		Information on risks related to properties causing the concern for the substance to be restricted / other properties. Information on other risks related to the alternatives.	PFAS are very persistent with a potential for exposure of humans via the environment. Short-chain PFAS accumulate in edible parts of plants and the accumulation in food chains is unknown[102] In general, there is a high level of uncertainty as to whether the ongoing exposure to low concentrations of short-chain PFAS may cause adverse effects in organisms. It is therefore very difficult to estimate long-term adverse effects in organisms. The constituents of alternatives are in general not persistent, and exposure via the environment is not considered to be of concern based on data currently available. For some alternatives, data are not sufficient to conclude that they do not include persistent constituents.				
	Risk to the environment	Information on the hazards: properties causing the concern for the substance to be restricted / other properties.	Alternatives do not generally meet the PBT or vPvB criteria. For some of the alternatives, data were not sufficient to determine whether some constituents are persistent. Many of the alternatives include constituents classified as toxic or very toxic to aquatic life.				
		Information on risks related to properties causing the concern for the substance to be restricted / other properties. Information on other risks related to the alternatives.	Short-chain PFAS are very persistent with high mobility in environmental media and high potential for long-range transport. * The constituents of the alternatives are in general not identified as persistent or of having a high potential for long-range transport and for accumulating in the environment. However, there was insufficient information available to conclude whether the underlying test/endpoint data was equivalent for these substances and the alternative products, compared to the PFAS-based products.				
	Assessment of net risk	Would the alternative result in a sufficient reduction in the net risk? Are there new risks associated with the alternative?	In general, alternatives do not contain very persistent substances and are considered likely to provide a reduction in the net risk. The main constituents of alternatives are typically used in cleaning and washing agents, food, etc. Overall, no significant new risks have been identified based on the available information. However, not all human health or environmental hazard endpoints have necessarily been assessed in detail for each component by the foam manufacturers (e.g. endocrine disrupting effects). Additionally, the level of information				

[102] Short-chain perfluoroalkyl acids: environmental concerns and a regulatory strategy under REACH. Brendel et al. 2018. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5834591/pdf/12302_2018_Article_134.pdf

Parameter		Questions	Airports	Off-shore facilities	Petrochemical industry and large tank farms	Municipal fire brigades	Marine applications
			available on the risk posed by some alternatives is insufficient to conclude whether the underlying test/endpoint data was equivalent compared to the PFAS-based products.				
Economic feasibility	Net costs	Net compliance and other costs (taking into account both increases and decreases in costs) faced by actors in each link of the supply chain.	One off costs: The main costs of transition are reported to be costs of replacement of PFAS-containing foams in storage and destruction of these foams (such costs would not normally have been incurred outside of normal replacement after 10-20 years). Total costs of replacement and destruction is approximately €6/l. Costs of decontamination of equipment have been mentioned by stakeholders as potentially significant, but actual cases do not indicate significant costs of decontamination. Recurrent costs: Extra costs of foams are reported to be in the range of 0 to +30%.				
		Economic feasibility of the alternatives.	Alternatives have successfully been implemented by many users	Alternatives have successfully been implemented by some users	Alternatives have successfully been implemented for training purposes; for specific applications alternatives are not available	Alternatives have successfully been implemented by many users	Alternatives have successfully been implemented by many users
		Ability of the different actors to pass costs down the supply chain.	High (no competition with competitors outside the EU)	Medium (some competition with competitors outside the EU)	Medium (some competition with competitors outside the EU)	High (no competition with competitors outside the EU)	Low (significant competition with competitors outside the EU)
		Trade and wider economic and employment effects.	No effect expected	No significant effect expected	No significant effect expected	No effect expected	No significant effect expected
Uncertainties.		What is the level of uncertainty in the assessment of the feasibility, risks and economic viability of alternatives?	High certainty	High certainty	Medium certainty - many different and complex scenarios	High certainty	High certainty

Note: * Short-chain perfluoroalkyl acids: environmental concerns and a regulatory strategy under REACH. Brendel et al. 2018. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5834591/pdf/12302_2018_Article_134.pdf

8. Task 2: The socio-economic impacts of substitution of PFAS-containing fire-fighting foams

8.1 Aims and scope of the SEA

The aim of the SEA

Along with an analysis of alternatives, the socio-economic analysis is key to understanding the potential impacts of a restriction. This is intended to evaluate whether a proposed restriction (if one is adopted) provides the best practical option to manage the risks, and if the benefits of controlling the risks identified do not generate disproportionate costs. The primary objectives of this task were to assess the socio-economic impacts of an EU-wide restriction or total ban of the use of PFAS-containing fire-fighting foam to inform the pre-RMOA and pre-Annex XV dossier.

Definition of the "baseline" scenario

The baseline scenario describes the situation in the absence of any further regulatory management options (RMOs). It reflects the current market situation, but also any anticipated changes in the absence of the proposed RMOs. It was used to compare restriction scenarios (defined in the next sub-section), to ensure that the SEA evaluates the impacts of the RMOs being assessed.

More details are provided in the market analysis (see Section 4), but the key points are below.

- It is estimated that currently some 14,000-20,000 tonnes (likely closer to the upper end of the range) of PFAS-based fire-fighting foams are sold per year in the EU and used in various sectors including chemicals/petrochemicals, municipal fire-fighting, marine, airports, military, railways and fire extinguishers. Their use is particularly important and widespread where there is a risk of Class B fires, i.e. where flammable liquids are present. They are used for fire-fighting, but in some cases also for training and testing of equipment;
- Some 9,000 tonnes per year of fluorine-free foams are already used in most of the same applications, although the split by sector varies from that of PFAS-based foams. Several stakeholders, including manufacturers of fire-fighting foams, have indicated that the use of fluorine-free foams has been increasing, particularly in applications where PFAS-based foams can be very easily replaced (e.g. training). This trend is expected to continue in the future to some extent (even in the absence of any restriction on PFAS-based foams). Some stakeholders also noted that containment of fire-water run-off, particularly from training, has been increasing and that this has likely reduced emissions of PFAS significantly;
- In addition, there are significant existing stocks of PFAS containing foams which have been already purchased. These may need to be disposed of and replaced. The total quantum of these stocks is uncertain, but are estimated as follows:
    - Annual sales of PFAS-based foams are estimated at between 14,000-20,000 tonnes per year;
    - Current annual sales of fluorine-free foams are estimated at 7,000-9,000 tonnes per year. Historically, this demand would have been served by PFAS containing foams, hence the total annual sales of PFAS-based foams could have been some 21,000-29,000 tonnes;

- The shelf life of PFAS-based foams is reported to be typically between 10 and 20 years (and up to a maximum of 30 years)[103]. Given that foams may be used before the end of their shelf life, the actual lifetime of foams could be shorter. BiPRO 2010 suggests that the average lifespan of fire-fighting foams is 15 years, which appears consistent with the above information[104]; and
- Given that between 14,000 and 29,000 tonnes of PFAS-based foam have historically been replaced per year, and assuming an average lifespan of foams of 15 years, indicates that the existing European stocks of PFAS-based foam may be between 210,000 and 435,000 tonnes[105]. These volumes of stock are used in the SEA calculations.

Identification and definition of the assessed regulatory management options

Two main restriction scenarios are considered in the following analysis:

> **Scenario 1:** Restriction (ban) on the **placing on the market** of PFAS-based FFF. The use of legacy foams, i.e. foams already in stock at producers' or users' sites, is still permitted. So, under this scenario, new sales would be prevented but existing stocks could be used and run down incrementally.
>
> **Scenario 2:** Restriction (ban) on the **placing on the market and the use** of PFAS-based FFF. In addition to a restriction on sale, legacy foams, i.e. foams already in stock at producers' or users' sites, should be disposed of safely. So, under this scenario, both new sales would be prevented, and existing stocks would need to be disposed of and replaced with new volumes of fluorine-free foams.

For both scenarios, the socio-economic implications of different conditions of the restriction are discussed. This includes uses/sectors and the merits of possible exemptions, transition periods, application of specific Risk Management Measures (RMMs) for specific uses of fire-fighting foams, as well as permitted residual PFAS concentrations in foams.

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[103] Proposal for a restriction: Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related substances https://echa.europa.eu/documents/10162/a22da803-0749-81d8-bc6d-ef551fc24e19

[104] BiPRO, 2010, Study on waste related issues of newly listed POPs and candidate POPs

[105] A lifespan of 15 years means that each year, 1/15 of the stocks are replaced. So, if between 14,000 to 29,000 tonnes are replaced per year, then the stock is 15 times that tonnage. Multiplying annual replacement tonnages with 15 yields the above estimates.

8.2 Analysis of the impacts

Overview

The two figures below summarise the main effects (i.e. anticipated responses from the supply chains along with associated impacts) resulting from the two restriction scenarios. These are identified based on literature review, the targeted stakeholder consultation, and discussions with the steering group. The large text in the solid green boxes summarises each effect in a brief headline, the smaller hollow boxes provide some additional commentary. The numbered boxes at the end of each chain represent the ultimate impacts to be assessed. These ultimate impacts are discussed one by one in the following subsections.

Figure 8.1 Map summarising potential effects of a restriction on the placing on the market of PFAS-based fire-fighting foams

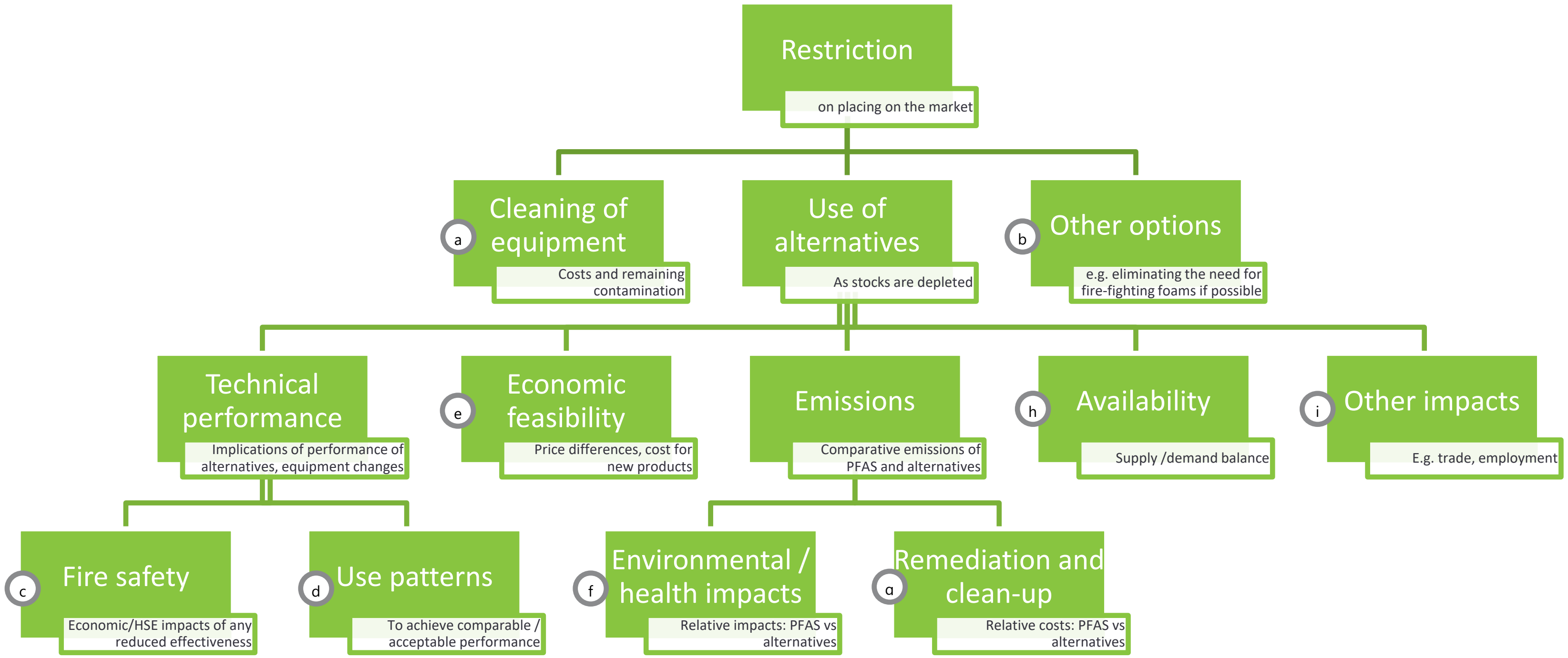
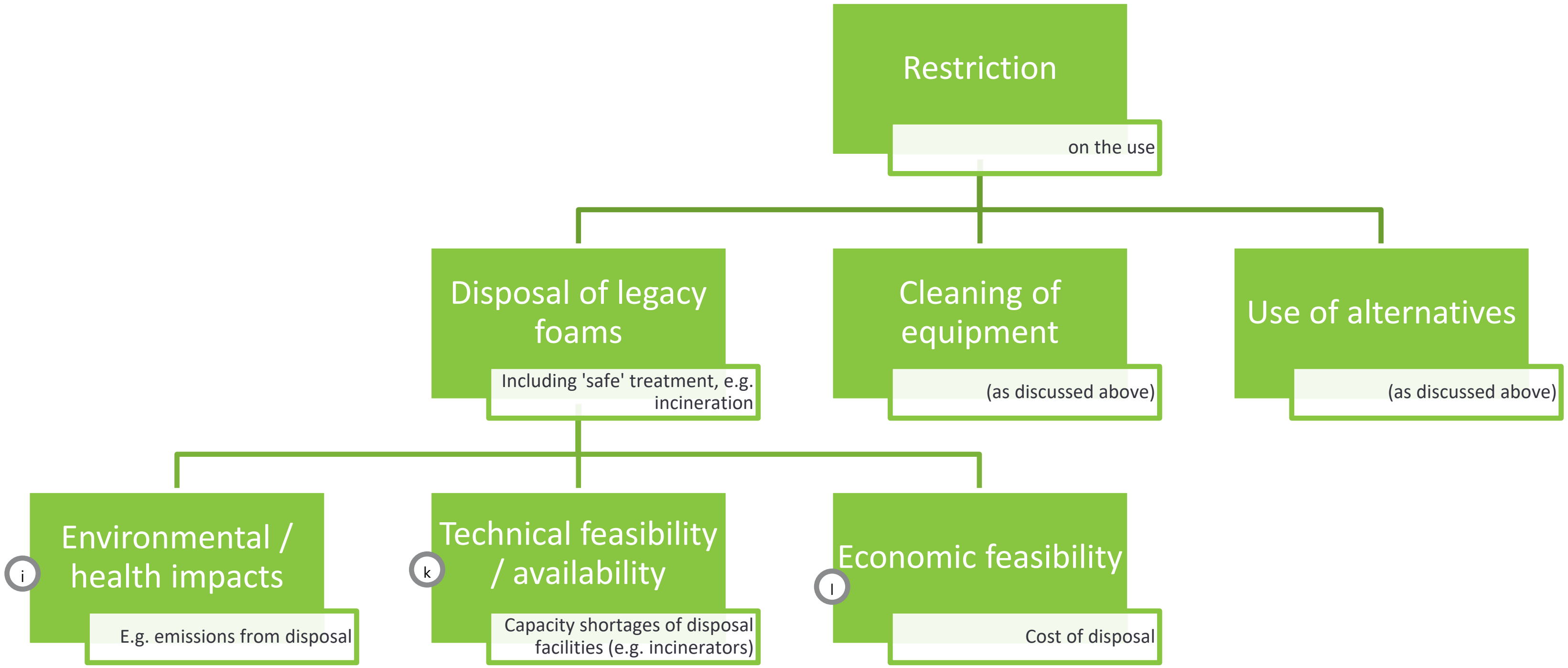


Figure 8.2 Map summarising potential effects of a restriction on the use of PFAS-based fire-fighting foams



a. Cleaning of equipment: costs and remaining contamination

A restriction on the placing on the market of PFAS-containing fire-fighting foams (Scenario 1) would allow users to continue using their stocks of foams, but once they are depleted, users would be forced to switch to alternative (fluorine-free) foams. A restriction on the use of PFAS-containing fire-fighting foams (Scenario 2) would require this switch to happen immediately when the restriction comes into force (or before).

During the storage of PFAS-containing foams, fluorinated surfactants settle on the walls of the tanks as well as in pipe and hose lines of fire-fighting equipment. These would leach into any new foams filled into the equipment and therefore contaminate the new fluorine-free foams with PFAS, leading to continued PFAS emissions[106]. In order to control these emissions, equipment previously used for PFAS foams may be required to meet a minimum concentration limit of remaining PFAS, which can potentially be achieved through cleaning. This sub-section discusses the feasibility of achieving a certain (yet to be determined) concentration of PFAS through the cleaning of equipment, with a focus on the associated cost. The analysis of alternatives has concluded that currently available cases of transformation to fluorine-free foams do not indicate significant costs of decontamination of equipment (including disposal of the liquid used for cleaning), with relatively simple methods being applied. However, the costs of cleaning of equipment will depend on the contamination thresholds requirements. According to information from manufacturers, it may in some instances be less expensive to change part of the equipment than to clean it, especially for stationary equipment, so this is also discussed below.

Techniques identified to clean PFAS-containing foam from equipment are:

- The use of **hot water and detergents** in a 32-stage legacy foam decontamination process (stakeholder consultation response). This technique is reported to result in all appliances achieving PFAS levels below 1000ppt and one-third of appliances being below 70ppt. An independent body oversees the process and measures the PFAS concentrations achieved. The approximate cost of this process is **€12,300[107] per appliance**.; and
- For stainless steel tanks, glass fibre reinforced plastic and polyethylene tanks, following the discarding of the foam, **tanks are rinsed with hot water (50-60°C) and then filled again with hot water for at least 24 hours[108]**. This process is repeated three times in both the tank and any foam carrying pipes and fittings, and the water from these rinsing operations passed into the sewage system and treatment plant. This is recommended in some government guidance[109]. No information could be identified concerning the costs of this technique or the remaining contamination levels achieved.

Several stakeholders commented on the feasibility of cleaning techniques to remove PFAS-containing foams from equipment. One stakeholder considered achieving PFAS contamination levels below 100 ppb to be unrealistic in most cases (from the stakeholder workshop) and one stakeholder considered it to be almost impossible to achieve a contamination level of zero in a one-digit ppb framework with another stakeholder also commenting that the cleaning of systems and equipment is unlikely to bring the level of residual PFAS to zero. One stakeholder that has transitioned to fluorine-free foams (in the petrochemicals sector) reported that they had aimed for and achieved a level of 0.001% (10,000 ppb). To put this into context, the average

[106] Bavarian Ministry of the Interior, Sport and Integration, and Bavarian Ministry of the Environment and Consumer Protection: Environmentally friendly use of fire-fighting foams. Available at: https://www.bestellen.bayern.de/application/eshop_app000000?SID=578672032&ACTIONxSESSxSHOWPIC(BILDxKEY:%27stmuv_all_00001%27,BILDxCLASS:%27Artikel%27,BILDxTYPE:%27PDF%27) [In German]

[107] Conversion rate of 1 EUR = 1.62470 AUD applied. It is assumed that this cost includes treatment of the waste water generated, although the stakeholder response did not specify that.

[108] https://www.bestellen.bayern.de/application/eshop_app000000?SID=578672032&ACTIONxSESSxSHOWPIC(BILDxKEY:%27stmuv_all_00001%27,BILDxCLASS:%27Artikel%27,BILDxTYPE:%27PDF%27 [In German].

[109] https://www.bestellen.bayern.de/application/eshop_app000007?SID=147496132&ACTIONxSESSxSHOWPIC(BILDxKEY:%27stmuv_all_00001%27,BILDxCLASS:%27Artikel%27,BILDxTYPE:%27PDF%27) [In German]

concentration of PFAS in PFAS-based fire-fighting foams is some 2-3% (20-30 million ppb). One stakeholder commented that the level of cleanliness achieved by cleaning techniques would vary depending on the equipment and material being cleaned. The need to accommodate an allowance for residual legacy PFAS even after equipment has been cleaned was also discussed.

Stakeholders also commented on how cleaning techniques and costs may be impacted by different PFAS contamination thresholds. Where contamination threshold levels are set high, following the cleaning of equipment, a higher level of residual PFAS-containing foam would be allowed to remain (compared to if a lower threshold limit were set). One stakeholder therefore considered the implementation of a high contamination threshold to be "pointless", due to its reduced effectiveness in eliminating PFAS emissions. With a low contamination threshold level, a lower level of residual PFAS-containing foam will be allowed to remain in equipment following cleaning and cleaning will be more costly than if a higher threshold level were set. Also, where contamination levels cannot be achieved through cleaning, equipment will need to be replaced at a cost. Equipment replacement is more likely to occur where threshold levels are set low.

There are potentially significant costs associated requirements for cleaning or replacement of equipment, if a low threshold is set for residual PFAS concentrations (following use of the alternatives in the same equipment as PFAS-based products). The market analysis (see Section 4.3) estimated that there are likely to be several tens or potentially hundreds of thousands of facilities with equipment that contains fire-fighting foams. If all of these require extensive cleaning using techniques such as the decontamination process described above (and costing €12,300 per appliance), the costs of cleaning could be in the region of €1 billion (based on an assumed 100,000 appliances needing cleaning). If a less stringent threshold concentration is used, the costs would potentially be significantly lower. However, insufficient information is available to develop a more robust estimate of these costs.

Regulation in Queensland, Australia, allows for threshold concentrations for replacement foam stocks to be 10ppm (mg/l) for PFOA/PFHxS and 50ppm (mg/l) for PFOA[110]. Additionally, one stakeholder commented that newer C6 foams are purer and have lower concentrations of impurities than older C6 foams and suggested that different threshold levels for different PFAS-containing foams may be required.

For confirmation that threshold levels have been achieved, cleaning techniques may need to be professionally endorsed or, following cleaning, the presence and concentration of remaining PFAS tested. Stakeholder responses **reported some concern over the suitability of existing methods to measure and detect the presence and concentration of remaining PFAS**. One stakeholder reported that measuring very low concentrations e.g. at ppb-concentration was not possible. One stakeholder suggested that following cleaning, an assessment should be undertaken at an accredited laboratory for verification that threshold levels have been achieved. Stakeholder responses suggested that laboratories are able to analyse down to a level of 30-150 ppb. In the REACH restriction on PFOA, a concentration limit of 25 ppb of PFOA including its salts or 1,000 ppb of one or a combination of PFOA-related substances was adopted, based on the capabilities of analytical methods according to the RAC's opinion on the restriction dossier. Information on the cost of analysis was not provided. A cost analysis concerning the measurement of cleaning success could therefore be done as part of this analysis.

Where threshold limits cannot be achieved through cleaning techniques or where cleaning techniques are too difficult or too costly to achieve, the replacement of equipment is likely to be required. The cost of replacing equipment will vary across industries and appliances. Table 8.1 provides an example of the potential costs for the replacement of fire extinguishers, where cleaning techniques do not succeed in attaining threshold concentration levels, or the cleaning process costs more than the cost of replacement. It is assumed that these costs represent only the replacement cost of the equipment and do not include the replacement cost of equipment plus foam, nor the cost of disposal of the old equipment. Figures for the total number of fire extinguishers existing and currently using PFAS-based foam have been obtained from the

[110] Obtained from stakeholder consultation. Also available online here: https://www.qld.gov.au/environment/pollution/management/disasters/investigation-pfas/firefighting-foam/policy-overview

Market Analysis (the lower end of the range is based on a Eurofeu position paper and the higher end considered a more uncertain high-level estimate based on extrapolation from German data and expert judgement). The stakeholder consultation also revealed that the cost for a new extra foam tank in a fire truck is €35,000 for a fire brigade providing industrial fire protection. However, information of the number of existing foam tanks containing PFAS fire-fighting foam was not provided and therefore cost analysis for their replacement has not been estimated.

Table 8.1 Estimated costs for the replacement of fire extinguishers in the whole of the EU

	€1 per replacement extinguisher	€3 per replacement fire extinguisher	€5 per replacement fire extinguisher
15 million fire extinguishers to be replaced	€15 million	€45 million	€75 million
90 million fire extinguishers to be replaced	€90 million	€270 million	€450 million

Note that these costs do not include the cost of foam disposal from cleaning. Estimated costs of fire extinguishers were obtained from stakeholder consultation and it is not clear whether the costs of fire extinguisher replacement include the cost of alternative fire-fighting foam, as well as the equipment. Costs of fire extinguishers range from €1-5, and have been interpreted as low (€1), medium (€3) and high (€5). All fire extinguishers are assumed to cost the same regardless of size and capacity.

Overall, stakeholders considered the cleaning of equipment to be a costly operation, but little quantification of costs was provided in the consultation, making it difficult to undertake a cost analysis. Several users have already transitioned from using PFAS-containing firefighting foams to PFAS-free firefighting foams. Several consultees report there to be no significant costs associated with new equipment required. Although some stakeholders also report the replacement of fire-extinguishing systems and the cleaning of equipment to be costly. The cost of cleaning existing equipment will likely depend upon how effective cleaning techniques are for each appliance, as well as on the threshold contamination levels set. Where equipment cannot be sufficiently cleaned to meet threshold contamination levels (yet to be determined), replacement will be required.

b. Other options and their impacts

This section discusses what other responses to a restriction than using alternatives are likely (if any), and their socio-economic impact. Theoretically, in response to PFAS-based fire-fighting foams becoming unavailable, users could respond by eliminating the need for the use of fire-fighting foams. As discussed in the market analysis, the main application for PFAS-based fire-fighting foams are class B fires (flammable liquids and gases). Hence, to eliminate the need for fire-fighting foams would (in principle) require stopping the use of flammable liquids or gases, or accepting a situation where fires are less well controlled than at present. While this may be possible in a limited number of specific applications where they are not crucial, it seems unlikely in most cases. The consultation has also not specified any likely other responses than using alternatives. Therefore, no other options are considered.

c. Fire safety: impacts of technical performance of alternatives

Both scenarios 1 and 2 would lead to a transition to alternative foams. The transition associated with Scenario 2 would be faster as existing stock would need to be disposed of at the same time. The key socio-economic issue under both scenarios is the likelihood of fires being extinguished effectively and without delay, compared to the situation using PFAS based foams.

The key issues in the technical feasibility of alternatives are three -fold. First, do the alternatives effectively put out fires so that life, environment and property are not at additional risk? Second, if so, are there delays in the duration over which the alternatives can address these fires, considering the technical ability to deliver greater volumes of foams to the fire? Third, do the alternatives have relevant and reliable safety standards so that downstream users can purchase and use these alternatives with confidence, making allowance for testing in users' specific systems?

This sub-section discusses the difference in the fire safety performance through the use of alternative fire-fighting foams. These effects are quantified where possible, and drawn out qualitatively where not. This section draws directly on the analysis of alternatives (AoA). As in previous sections, whilst the AoA started with a long-list of some 30 alterative foam products, it focussed on a subset of seven judged to be illustrative of the efficacy of these. The evidence below focusses on these specific products but refers to wider evidence were relevant. Table 8.2 provides a summary of the key information.

Table 8.2 Effectiveness of alternatives – summary

Alternative	Attained performance standards?	Information from 'real world' use	Additional stakeholder information
Respondol ARF 3-6%	Yes - 2 (EN 1568 Parts 3 and 4)	None Identified	Can be used for use in 'all types of flammable liquid fires'.
RE-healing foam RF3X6 ATC	Yes x 4 (EN 1568 Parts 1 and 2, and ICAO Levels B and C))	Yes – Copenhagen Airport & Norwegian Offshore oil sector and Melbourne Fire Brigade.	Has been in used in Municipal Fire Brigade applications – both in training and operational fires.
RE-healing foam RF1-1%	Yes – 1 (EN 1568 Part 3)	Yes – Norwegian Offshore oil sector.	Consultees state this alternative can be used at offshore oil installations and onshore terminals and refinery.
Moussol FF 3X6 (F-15)	Yes x 5 (DIN EN 1568: Part 3 (Heptane): IIIB/IIID, Part 1: Medium ex. - Part 2: High ex. ICAO Low expansion foam - Level B DIN EN 3 21A).	Yes –Swedavia, Heathrow Airport (UK), Norwegian Petrochemical sector.	Has been in use at Heathrow Airport (UK) since 2012. See case study.
Foam Mousse 3% F-15	Yes (x1) (EN 1568 Part 3 heptane)	None identified (but consultation has confirmed this is in use)	Consultees state this alternative is largely used in marine applications and is only used for smaller fires (unsuitable for aviation, for example).
Epocol Premium	Yes x 6 and 1 in progress. EN 1568 - 1: Conform EN 1568 - 2: Conform EN 1568 - 3: 1A / 1A EN 1568 - 4: 1A / 1A Oil industry: LASTFIRE Forest fire standards: CEREN Certificate Certification in progress : UL 162 / GESIP).	None identified (but consultation has confirmed this is in use)	Manufacturer states this alternative can be used in all sectors: airports, marine, military, chemicals, oil and gas, municipal fire fighters and from fixed mobile and CAFs. Hydrocarbon fires, all types of flammable polar solvent liquids Consultees indicated this as a possible substitute for large tank fires, but further testing was necessary.
Orchidex Blue Foam 3x3	Yes x 4 (EN 1568 Parts 3 and 4, Oil industry: LASTFIRE, ICAO Level B))	Yes – German airport are reported to be using the product.	Consultees indicated potential for additional volumes and/or time to suppress fires may occur for some fuel types, but for others, the performance is the same as for PFAS foams.

Effectiveness of foams

The central finding, based on evidence from the analysis of alternatives, the stakeholder consultation and the workshop is that from a technical standpoint, no stakeholder concluded that alternatives are not technically feasible, at least for the majority of uses.

As noted in the AoA, in aviation several airports have successfully transitioned, as have Municipal Fire Brigades and companies active in offshore oil and gas operations and the marine sector. Evidence indicates that one segment - liquid fuel fires of large atmospheric storage tanks – is a concern for consultees. Large scale tests for fluorine free foams are ongoing and not yet complete, partly because the scale and cost of these tests. However PFAS-free foams have provided equivalent performance to C6 foams during hydrocarbon tank fires of 15, 60 and 80m diameter (during LASFIRE testing). Performance depends on application rate and equipment, but one stakeholder suggested that there is no real reason why these results cannot be extrapolated to bigger tanks (100m) or bund fires. More testing is required to prove performance of alternatives under some conditions. To date, no real-world examples of a successful transition in installations with large tanks are identified. Consultation has noted that, as such, AFFFs are still used when large fuel areas need to be extinguished quickly or in sprinkler systems.

The available evidence suggests that elsewhere technically feasible fluorine free foams have been developed, are commercially available and have been used to the satisfaction of users.

This transition has not occurred without some technical challenges (and cost) and has required testing in each users' system. Additional volumes of foam, compared to PFAS-based products, have been necessary, but not uniformly. Several users have identified – and overcome – technical issues. These related to temperature tolerance of alternatives and the viscosity of foams. Some changes to foam delivery systems, nozzles and some additional storage capacity has been required.

Speed of fire suppression (making allowance for additional volumes required)

Limited detailed information was obtained on this specific aspect. One respondent highlighted there could be a 5-10% gap in the extinguishing time, but that this "mainly" concerned polar liquids. Other consultees noted that equivalent volumes were required and these yielded equivalent performances, but this was not consistently reported. Others noted additional volumes of fluorine free foams, compared to PFAS based products in at least some applications. Some consultees highlight that this was a particular concern with small extinguishers. Whilst one respondent noted that, in general, fluorine free foams are less flexible for users, because they have less margin for error in the proportioning (i.e. volumes required), in their application type and of ease of use. However, other consultees provided feedback of use in specific applications (aviation), including an example of where a fluorine-free foam worked satisfactorily despite deliberate inappropriate application methods as part of testing procedures.

Standards

The analysis of alternatives (Section 7.5) provides a list of specific international compliance standards for the various commercially available products, with more details for each shortlisted product above. Appendix 5 provides more detail on each of these standards.

Foams are developed to meet specific standard requirements and it is important to note that tests used for standardisation and certification of PFAS-based foams are not necessarily appropriate for fluorine-free foams. Stakeholders highlighted during the consultation workshop that current testing protocols have often been designed with PFAS-based foams in mind. These testing protocols may not be adequately tailored to reflect the fire-fighting ability of fluorine-free foams, because the same application methods may not always be applied and read-across between different burning fuels may not be straightforward. Therefore, it is inherently challenging to compare the two types purely based on certification. Some fluorine-free foams are however capable of meeting standard firefighting certifications applicable to PFAS-based foams and this has been demonstrated in cases where some airports and municipal fire brigades for example have successfully transitioned to fluorine-free foams.

d. Use patterns of alternative fire-fighting foams to achieve comparable/acceptable performance

This section discusses the impacts associated with the use patterns of alternative fire-fighting foams and includes discussion on: (a) the quantity of alternative foams needed to achieve either comparable performance or performance that is acceptable from the standpoint of safety to PFAS foams. (b) different specific application methods and equipment used.

a) Quantity of foams needed to achieve comparable/best possible performance

The available evidence does not permit a quantitative estimate for the comparative volumes of fluorine free foams required, for each application and with specific foams. However, the consultation allow a range to be specified. The same approach is used for the availability assessment below. It is important to note that the available quantitative information received – despite extensive attempts for specific information and for clarification – was very limited. Based on the available data, the range specified was between no change in volume and up to a maximum of 100% additional foam required, note the 100% volume estimate was specified by just one consultee and it is understood that this relates to use in one application. The available information is not sufficient to conclude these are isolated cases. As noted in the previous section, this does not apply to liquid fuel fires of large atmospheric storage tanks/large scale tank fires. Here, consultation indicates that large scale testing is still needed to confirm performance.

The details on specific shortlisted products – which are known to be in use within the EU (based on stakeholder consultation) – are set out below.

Table 8.3 Use patterns of alternatives – summary

Alternative	Comparative volumes required vs PFAS containing foam
Respondol ARF 3-6%	No specific data has been supplied, despite attempts to obtain this via consultation.
RE-healing foam RF3X6 ATC	Variable depending on application ("drop in replacement, with no additional volumes required in offshore oil installations, onshore terminals and refinery).
RE-healing foam RF1-1%	No difference to PFAS based foams (evidence available for some applications only).
Moussol FF 3X6 (F-15)	Volumes vary depending on application. From no difference to up to c. double the volume required in some applications.
FOAMMOUSSE 3% F-15	No information available.
Epocol Premium	Range depending on application. Whilst stakeholder data is limited and relates to just one consultee, the potential ranges specified were between 30 - 50% greater volumes required. It is not clear whether the latter figure is only in exceptional circumstances.
Orchidex BlueFoam 3x3	Consultation data unclear – potential need for up to 10% additional volumes.

b) Specific application method for the foams or equipment used (if different for alternatives compared to PFAS-based foams)

Several respondents report that for fluorine free foams used in sprinkler applications, special sprinkler nozzles have to be installed, which included "special low expansion nozzles". For extinguishers, consultees noted that greater expansion is required for PFAS free foams. Therefore, depending on the extinguisher, pressure may need to be increased and different nozzles required.

Respondents also referred to challenges associated with temperature tolerance and viscosity of alternative foams. These appeared to have been satisfactorily resolved. Another noted that, as the chemical nature of the fuel varies, more than one agent may need to be stocked by users so that they may be able to deal with fires of different types on any one site. This was reported to be a reflection of a lower level of "flexibility" in Fluorine free foams. This has logistical, training and safety implications for users. The correct foam agents will need to be stocked, in appropriate locations, with ease of access along with processes and training to ensure users cannot use incorrect foam agents, particularly in fast moving emergency situations. Again, further specific information was not available to enable conclusion as to whether this risk applies differently to specific user sectors.

e. Impacts associated with the economic feasibility of alternatives

This section discusses the economic feasibility of alternatives. There are several elements assessed. First **annual** foam costs – based on the additional volumes required by industry in any one year, this is evaluated based on the price differences between alternative and PFAS-based foams are evaluated, considering whether additional volumes of the alternative are required to fulfil the same/acceptable functionality. So this is in effect, the cost for one annual replacement "cycle" as foams are used and/or disposed of as they pass their useful life. The net change in foam costs is then estimated. This is relevant for both Scenarios. Second, in Scenario 2 users would no longer be able to use the **foam stocks they have purchased**. The costs for this stock will have to be written off and new stocks purchased.

A **range of other costs**, associated with testing (and other R&D), storage, technical changes in foam dispensing and/or storage equipment and regulatory approvals are also summarised. The likelihood of whether additional costs would be passed down the supply chain is also considered.

Lastly, costs may be partly offset by **savings of using alternatives**, e.g. from less costly waste management when they reach their expiry date.

The assessment is associated with significant uncertainty and this is reflected in the wide ranges presented. There are uncertainties in several input assumptions, summarised in Table 8.4.

- Existing use of PFAS based foams is between 14,000 and 20,000 tonnes per year. The best estimate used in the analysis is some 18,000 tonnes per year;
- The average price of existing PFAS-based foam is subject to uncertainty, reflecting the wide range of specific foam compounds used. It is understood that certain compounds are currently available containing high proportions of PFAS and, whilst these are judged to be effective foams, the price for these compounds is well above average, the market assessment noted that these are uncommon. The weighted average used is €3,000 per tonne of PFAS containing foam, as set out in the market assessment. Note the lowest and highest values identified in the market assessment and stakeholder consultation were €2,000 per tonne and up to €30,000 per tonne. The latter figure has a significant effect on the ranges in the socio-economic assessment, but there is insufficient data to conclude the extent of the market currently pay this price per tonne for product;
- Based on these parameters, the current baseline foam costs are somewhere between €28 million per year and a maximum of up to €600 million per year. The best estimate is current costs of €54million per year (i.e. €3,000 multiplied by 18,000 tonnes);
- The same uncertainties apply to the average prices per tonne of fluorine free foams. The market assessment concludes, based on information provided via the stakeholder consultation, that fluorine free foams, on average, are likely to be the same price, i.e. around €3,000 per tonne of foam. This value is used in the central estimate. The ranges in the table below are the lowest and highest prices quoted in the consultation, respectively. This indicates that the most expensive fluorine free foam is likely be less expensive than the most expensive current foams. As noted above, this has a significant effect on the result and is subject to particular uncertainty; and
- Finally, consultees noted a range of different volumes may be required to fulfil the same/acceptable functions. The comparative volumes required differed, depending on the

specific application and customer need. Therefore, a range has been used, between a 0% increase and up to 100%more fluorine free product, over and above the volumes required for PFAS-based foams.

Costs for one annual cycle of foam replacement (Total EU market)

Table 8.4 summarises the assumptions used in the following to estimate annual foam replacement costs.

Table 8.4 Annual foam costs – input assumptions

Baseline PFAS foam market t/yr Central (L-H)	**Average price €/tonne of foam** Weighted average (L-H)	**Current foam costs (PFAS) EU market cost per year** Best estimate (L-H)	**Average price per tonne of foam (Fluorine free alternatives)**	**Additional volumes required % increase over PFAS based foams)** L-M-H
18,000 (14,000-20,000)	**€3,000** (€2k-€30k)	**€54m** (€28m - €600m)	**€3,000** (€0.7k-€10k)	**0% - 50% - 100%**

Source: Market assessment, desktop research and stakeholder consultation exercise. Note, the maximum baseline used in the SEA is 21,000 tonnes, rather than the 20,000 in the market assessment due to rounding of volumes used at sector level.

Using the assumptions above, Table 8.5 sets out the potential costs expected to be incurred by the EU market as a whole through purchasing volumes of fluorine free foam in an annual cycle. Overall, this suggests demand for alternative foams of between 14,000 tonnes per year and up to a maximum of 40,000 tonnes per year, for the sector as a whole. The associated costs are estimated at between €21 million and €30 million per year, with c. €27 million considered to be the most likely average cost for the EU market as a whole. Again, it is recognised that individual companies/users would incur greater or lower costs per tonne and require differing volumes. The wide ranges in different foam costs indicates whilst the average company may experience some increases in costs, others would experience savings, potentially quite large savings for some very specific market segments.

Table 8.5 Scenarios, gross and net foam costs –annual cycle replacement costs for total EU market (m denotes millions)

	Costs for existing PFAS based foams (EU Market) – best estimate (Range)	**Tonnes of alternative required (EU Market) (L-M-H)**	**Potential foam costs using alternative products (EU Market) Best estimate (Range)**	**Net change in foam costs (EU market) Best estimate (Range)**
Best estimate (assuming 18,000t) PFAS foam use p/yr)	**€54m** (€36m - €540m)	18,000 - 27,000 - 36,000	**€81m** (€13m to €360m)	**€27m** (-€23m to -€180m)
Assuming low PFAS foam use (14,000 t/yr.)	**€42m** (€28m - €480m	14,000 –21,000 – 28,000	**€63m** (€10m - €280m)	**€21m** (-€18m to -€200 m)
Assuming high PFAS foam use (20,000 t/yr.)	**€60m** (€40m - €600m)	20,000- 30,000 – 40,000	**€90m** (€14m- €400m)	**€30m** (-€26m to -€200 m)

Source: Market assessment, desktop research and stakeholder consultation exercise.

It is important to note that the stakeholder consultation indicated many users had experienced no increase in foams costs and indeed no additional volumes required. The above has been undertaken to assess the potential scale in a best and worst case, using reasonable assumptions in the absence of complete data.

Costs for stock write off and replacement (Total EU market)

In addition to the annual replacement cycle, under Scenario 2 the entire stocks of PFAS foam would need to be disposed of and alternative volumes of foam would then need to be purchased. In the baseline, foam stocks would also have to be replaced once they are used or expired, so the restriction would bring the replacement costs forward. To reflect this, the value of the depreciation of stocks at the point of replacement due to the restriction is also considered. Assuming an even age distribution of stocks of PFAS-based foam and a linear depreciation of foams over their lifetime, the restriction would cut the life of the foams in half on average, and so half of their original purchase value would already have depreciated and should not be considered as a cost of the restriction. The restriction could also cause additional cost of purchasing alternatives instead of PFAS-based foam taking account of both the price differential and the potential difference in volumes required. As above there is significant uncertainty in the input assumptions and these are presented as a possible range of costs.

Table 8.6 Quantitative data - economic costs

Baseline	**Existing stocks of PFAS-based foam**: Average: 322,500 (Between 210,000 tonnes and 435,000 tonnes)	**Purchase costs (one-off total for whole stock):** Average: €970 million (range €420 million to €13 billion)	**Value of stock depreciated**: Average: €485 million (range €210 million to €650 million) (half of purchase cost, assuming even age distribution and linear depreciation)
Restriction Scenario	**Volume of replacement with fluorine-free alternatives:** Average: 483,750 (Between 210,000 tonnes and 870,000 tonnes)	**Purchase costs (one-off total for whole stock) :** Average: €1.5 billion (range €150 million to €9 billion)	**Additional cost of the restriction**: Average: €1.0 billion (range-€60 million - €8.3 billion) (Purchase cost of replacement minus value of existing stock depreciated)

Based on PFAS foam costs of €3,000 per tonne weighted average (with lowest costs of €2,000 and highest of up to €30,000 per tonne) and fluorine-free foam costs of €3,000 per tonne weighted average (with lowest costs of €700 and highest of up to €10,000 per tonne)

The cost of the foam itself are only one aspect of the economic considerations of adopting alternatives. Additional transitional costs are described below. It has not been possible, despite attempts to obtain further quantitative information, to estimate costs for the market as a whole. However, several consultees noted that whilst additional costs were incurred, these were not significant and had proved manageable. Available quantitative information is summarised below. Further information is also presented in the case studies. Note that the cost of disposal of stocks of PFAS foam is covered in a later subsection (I. Costs of disposal of legacy foams).

Table 8.7 Quantitative data - economic costs

Testing costs	Storage costs	Costs from technical changes	Other costs including regulatory approvals
No quantitative data has been obtained via stakeholder consultation, despite several requests for such information. Testing would be associated with costs for sample volumes of	Experience in the Norwegian petrochemical sector (Equinor) included additional costs related to purchasing additional volumes of foam, to replace the previous PFAS	Consultation indicated that new nozzles had been required in several cases. Typical costs for a range of firefighting nozzles are within an approximate range	Experience in the Norwegian petrochemical sector (Equinor) indicates costs (labour time) in the region of €360,000 for a range of support in their transition at

Testing costs	Storage costs	Costs from technical changes	Other costs including regulatory approvals
foam (likely several different products) and with staff time and training.	containing foams, no information was provided on whether there were costs implications related to the need for additional storage space..	of between €5 or less, per piece for simple foam nozzle devices, to c. €30 and up to c.€60 for marine firefighting nozzles or "heavy duty applicators" and up to c €200 for more specialist equipment [1] Mobile foam units are in the region of €2,700 [2]	a total of 45 sites (so in the order of c. €10,000 per site). This would therefore appear to be an upper bound cost for a company transitioning.

Notes
[1]: Costs derived from search of widely available commercial products. See: https://www.made-in-china.com/products-search/hot-china-products/Water_Foam_Nozzle_Price.html See also https://www.orbitalfasteners.co.uk/products/heavy-duty-foam-dispenser-gun See also: https://www.dortechdirect.co.uk/heavy-duty-pu-applicator-gun-for-expanding-foam.html?gclid=EAIaIQobChMIudKHq9GP5gIVSbDtCh31AATEEAQYASABEgL5S_D_BwE See: https://www.safetyshop.com/lever-operated-nozzle-for-fire-hose.html?gclid=EAIaIQobChMI6cKnwNmP5gIVAuDtCh2KMwErEAQYAiABEgL91PD_BwE&gclsrc=aw.ds See: https://www.fireprotectiononline.co.uk/hv-series-low-expansion-foam-branch-pipes.html?gclid=EAIaIQobChMItqqg_NmP5gIViLbtCh0ImgYXEAQYByABEgIFdvD_BwE
[2]: https://simplyextinguishers.co.uk/df130-mobile-foam-units.html?gclid=EAIaIQobChMIn4yv79yP5gIVgpOzCh1-PQghEAkYBiABEgKsIfD_BwE

Testing costs

Whilst there are several categories of foam designed to address fires from specific fuels, consultation stressed that there are many more different types of overall fire systems, each with slightly different requirements. There is evidence that several downstream users are currently testing fluorine free firefighting foams, and that several others have now successfully transitioned. All stressed the importance of testing the foam compounds. This imposes costs in purchasing (possibly several different types of product), along with storage, training of personnel, performance monitoring and evaluation, disposal and clean-up. Consultees also noted costs from periodic testing of the fluorine-free products once in storage, to ensure that performance is not degraded; this was in the context of some initial uncertainty over shelf life for some products, which now appears to have been addressed. Whilst these costs were acknowledged, the evidence indicates they are one-off, comparatively small and were absorbed by the downstream users.

Storage costs (including storage during transition)

Whilst technical performance of alternatives was concluded to acceptable in most cases, some noted a "higher sensitivity" of fluorine free foam, compared to PFAS based foam; i.e. they allow for less flexibility in use, requiring multiple types of foam to be stocked. The is associated with costs in purchasing foam, of storage capacity – particularly during a transition when both PFAS based and fluorine-free may have to be stored - as well as some training costs. Where evidence has been provided in the stakeholder consultation, it was noted that these costs were manageable and could be mitigated via phased transition. It was acknowledged these costs are generally greater for fixed than for mobile applications, and where larger volume are used and stored.

Costs from technical changes

No consultees indicated that a transition from PFAS-based foams to fluorine-free required investment in entirely new foam delivery systems. However, problems have been encountered in specific components: such as proportioner pumps, jets and nozzles for discharge, including the need for replacement nozzles; including low expansion nozzles. These challenges appear to have been caused by differences in foam viscosity. Typical costs for a range of firefighting nozzles are within an approximate range of between €5 or less per piece for simple foam nozzle devices, to c. €30 and up to c. €60 for marine firefighting nozzles or "heavy duty applicators" and up to c €200 for more specialist equipment[111]. Mobile foam units are in the region of €2,700.[112]

Other costs

These include regulatory approvals and those associated with bringing new products to market. Given that the market assessment noted at least some current use of fluorine free products in all sectors, further adopting fluorine-free foams would appear to be a continuity of an existing transition – so a lot of the initial costs associated with new products development will have already been incurred. Experience in the Norwegian petrochemical sector (Equinor) indicates costs (labour time) in the region of €360,000 for a range of support in their transition at a total of 45 sites (so in the order of c. €10,000 per site).

Savings from adoption of fluorine free foam

Many stakeholders acknowledged potential for savings from use of fluorine-free foams. The potential savings resulting from a reduction of firewater that requires disposal and hence the costs of disposal as well as from avoided long term liability for site contamination/ remediation and clean-up costs are discussed further in subsection "g. Remediation and clean-up".

However, fire-fighting foams may also need to be disposed of when not used at the time of their expiry date. As discussed in more detail in Section "j. Emissions from disposal", incineration is considered the most appropriate disposal option for PFAS-based foams. The disposal method for fluorine-free foam would depend on the hazards of the specific foam. However, in general they are expected to exhibit lower hazards and higher biodegradability, so it is likely that they require less costly disposal methods, such as waste water treatment. While no specific data was available to estimate the disposal cost of fluorine-free foams, the costs of incinerating PFAS-based foams is expected to be typically around €1 per litre (range €0.3 to €11, see Section "l. Costs of disposal" for more detail).

As discussed in the emission assessment in Task 3 (Section 5), a number of references suggest usage rates of around 15-20% of existing stocks per annum, with an AFFF shelf-life of up to 15 years, which would suggest all foam concentrate is used before expiration, while other sources suggest that significant quantities of expired foam concentrate is indeed destroyed. If the usage rate of 15-20% per annum of existing stocks is an average across all sectors of use, there will be some installations with potentially far lower usage rates annually that will likely have some foams that reach expiry before use. In the absence of specific data, below the potential costs are shown for 1%, 5% and 20% of annual foam purchases replacing foams that have reached their expiry date[113]. Note that these figures are hypothetical and are shown to illustrate the potential order of magnitude only:

[111] Costs derived from search of widely available commercial products. See: https://www.made-in-china.com/products-search/hot-china-products/Water_Foam_Nozzle_Price.html See also https://www.orbitalfasteners.co.uk/products/heavy-duty-foam-dispenser-gun See also: https://www.dortechdirect.co.uk/heavy-duty-pu-applicator-gun-for-expanding-foam.html?gclid=EAIaIQobChMIudKHq9GP5gIVSbDtCh31AATEEAQYASABEgL5S_D_BwE See: https://www.safetyshop.com/lever-operated-nozzle-for-fire-hose.html?gclid=EAIaIQobChMI6cKnwNmP5gIVAuDtCh2KMwErEAQYAiABEgL91PD_BwE&gclsrc=aw.ds See: https://www.fireprotectiononline.co.uk/hv-series-low-expansion-foam-branch-pipes.html?gclid=EAIaIQobChMItqqg_NmP5gIViLbtCh0ImgYXEAQYByABEgIFdvD_BwE

[112] https://simplyextinguishers.co.uk/df130-mobile-foam-units.html?gclid=EAIaIQobChMIn4yv79yP5gIVgpOzCh1-PQghEAkYBiABEgKsIfD_BwE

[113] It is also assumed that all PFAS-based foams are incinerated, although it should be noted that not all PFAS-based foams are currently incinerated when they reach their expiry date (e.g. some of them are used for training), so this is likely an overestimate.

Total foam purchased per year (tonnes)	% of annually purchased foam replacing foams not used (hypothetical)	Foam to be disposed of per year (tonnes)	Cost of disposal: €0.3/l (low)	Cost of disposal: €1.0/l (best estimate)	Cost of disposal: €11/l (high)
14,000 (low)	1% (low)	140	42,000	140,000	1,540,000
18,000 (average)	5% (central)	900	270,000	900,000	9,900,000
20,000 (high)	20% (high)	4,000	1,200,000	4,000,000	44,000,000

Sources: Foam tonnage per year based on Eurofeu data (see Section 4.3), disposal costs per litre based on Section 8.2 "I. Costs of disposal".

Based on the total foam purchased per year, foam disposal costs per litre and hypothetical shares of foams not used per year, it is estimated that the annual costs of PFAS-based foam disposal could be between some €40,000 and some €40 million, but more likely (as a central estimate) in the order of million Euros.

Other potential benefits noted by consultees include emerging concerns over corporate reputation from continued use of PFAS foams and savings from avoided cross contamination of other waste streams, from monitoring, environmental permitting requirements, controls and personal protective equipment.

Despite additional stakeholder consultation, and some specific examples of savings, it has not been possible to provide an overall estimate of these savings for the market or average firm. The savings were however noted as "significant" by several consultees.

f. Environmental/health impacts of alternatives

This section discusses the environmental and health impacts of alternatives to PFAS foams, in comparison with PFAS-based foams. A quantitative comparison of emissions and the associated risk under each scenario was not possible with the available data. The assessment focusses on the overall assessment of risk set out in Section 5 alongside an evaluation of the hazards and risks of most likely alternatives.

The evaluation in task 3 concluded, based on analysis of PNECs and data on biodegradation and bioaccumulation, that the two fluorinated substances (used as examples) are of higher environmental concern compared to the non-fluorinated substances when it comes to hazard for the environment. This reflects the former's non-biodegradable nature, along with the relatively low PNECs for water and soil. Some of the alternative substances also exhibit low PNECs, but are readily biodegradable. The assessment in task 3 notes that further work would be needed to assess the risks associated with specific sites or food production pathways.

Table 8.8 provides an overview of the hazards of the shortlisted alternatives based on information from the foam Safety Data Sheets (SDS). None of the components included in the Safety Data Sheets are classified with CMR properties. In terms of PBT/vPvB properties, whilst none of the alternatives include substances *demonstrated* to be PBT or vBvP substances, for two products insufficient data are available and tests had not been concluded for a third. The hazard posed by PFAS foams compared to the constituents of the alternative fluorine-free foams are considered further in Section 5. However, a review of potential hazards based on PNECs, biodegradation and bioaccumulation shows that fluorinated substances (in PFAS-based foams) are of higher priority compared to the non-fluorinated substances (in fluorine-free alternatives) when it comes to hazard to environment. This is due to the fact that some PFAS are not readily biodegradable, are mobile and have relatively low PNECs for water and soil. Some of the substances used in the alternative products do however exhibit low PNECs, but this needs to be considered in the context of biodegradation and so far data is not available to examine these in detail.

Table 8.8 Overview of key hazards of alternatives based on information from SDS

	CMR Properties	PBT or vBvP Criteria?	Other HH concerns indicated in SDS	Other Env concerns indicated in SDS
Respondol ATF 3-6%	No	No	Skin and serious eye irritation (H315, H319)	None
Re-Healing Foam RF3x6 ATC	No	Uncertain (insufficient data on SDS)	Serious eye irritation (H319)	None
Re-Healing Foam RF1 1%	No	Uncertain (insufficient data on SDS)	Skin irritation and eye damage (H315, H318)	Aquatic Acute 1 (H400)
Moussol FF 3x6 (F-15)	No	No	Serious eye irritation (H319); damage to kidneys if swallowed (H373)	Can harm aquatic fauna, can harm bacteria population in WWT plants
FOAMOUSSE® 3% F-15	No	No	Harmful if swallowed (H302), skin irritation and serious eye irritation (H315, H319)	None
Ecopol Premium	No	No	Serious eye damage (H318)	None
Orchidex BlueFoam 3x3	No	Not tested	Harmful if swallowed (H302) and serious eye irritation (H319)	Harmful to aquatic life with long lasting effects (H412).

g. Remediation and clean-up

This section discusses the economic implications in terms of reduced requirements for remediation potentially resulting from a restriction on PFAS-based fire-fighting foams under Scenario 1 or 2. Both scenarios will require a transition to alternatives. This means that in both Scenarios, emissions of PFAS related to fire-fighting foam use will cease. In Scenario 2 they will cease immediately upon the restriction taking effect, while under Scenario 1 further use, emissions and site-contamination could presumably take place. Emissions of the substances used in the alternatives would likely increase proportionately, assuming no additional containment measures compared to the current use of PFAS-based foams.

Remediation

Task 4 of the DG ENV study ('Remediation costs and technologies', see Section 0) has assessed the typical costs of remediation of PFAS contamination resulting from the use of fire-fighting foams. The results are summarised in the table below. This shows that the typical costs per site can range from around half a million Euros (only soil remediation required, lower estimate) to just over €100 million (sum of soil excavation and incineration, groundwater pump and treat and drinking water reverse osmosis, higher estimates).[114]

[114] Please note the caveats highlighted in Section 0. Notably, remediation costs are highly site-specific and in certain cases can exceed the ranges provided. The estimates should therefore be considered order-of-magnitude cost ranges.

Table 8.9 Typical cost per site of remediation of PFAS contamination resulting from the use of fire-fighting foams

Compartment	Technique	Cost
Soil	Excavation and off-site disposal	€ 0.5 – 18 million
	Excavation and incineration	€ 2.5 – 38 million
	Capping	€ 0.42 - 4.3 million
Groundwater	Pump and treat	€1.2 – 30.3 million
Drinking water	Reverse osmosis	€2.9 – 39.8 million

Source: Wood 2019, see Section 0 for more details.

Task 3 of the DG ENV study ('assessment of emissions and hazard of fluorine-free foams', Section 5) has shown that the substances contained in fluorine-free alternatives exhibit lower concern than PFAS used in fire-fighting foams, due to their lower hazards and more rapid biodegradation. On this basis, Task 4 of the DG ENV study has concluded that it is currently not predicted as likely that remediation will be required as a result of the use of fluorine-free alternatives. Therefore, no remediation costs are expected to be incurred from the use of fluorine-free alternatives, implying potential savings from substitution of PFAS-based foams.

It is important to note that the costs refer to the remediation of legacy contamination that occurred from historical fire-fighting and/or training activities. In particular, training activities, which account for the majority of fire-fighting foam use, either already avoid the use of PFAS-containing foams and/or are conducted at contained training facilities, according to current best practice. However, the consultation did not yield information on the extent to which best practice measures are being implemented, or their effectiveness. Task 3 of the DG ENV study has estimated that the current levels of emissions from training are likely relatively low; however historical emissions are understood to have been much higher.

Fire-fighting activities typically require more immediate clean-up (discussed further in the next paragraph) rather than long-term PFAS remediation. On this basis, it seems unlikely that the current use of PFAS-containing fire-fighting foams would lead to the same remediation costs as presented for legacy contamination above. In conclusion, the restriction scenarios could eliminate the potential risk of PFAS contamination which could cause costs of up to around €100 million per site. There are large uncertainties in the numbers of sites that may require remediation and remediation costs are very case-specific and would differ significantly across these sites, so the following estimate of total remediation costs caused by the use of PFAS-based fire-fighting foams is indicative only:

- The market analysis (see Section 4.3) estimated that there are likely to be several tens or potentially hundreds of thousands of sites that use or at least possess fire-fighting foams;
- If all of these would require remediation (costing some €10s of million per site), the costs of cleaning could be at most in the region of trillions of Euros (based on an assumed 100,000 sites needing remediation);
- However, in reality only a much smaller number of these sites would use PFAS-based foams in sufficient quantities and without adequate containment and immediate clean-up to require large scale remediation. More information on the total number of sites, real-world use of PFAS per site as well as implementation and effectiveness of best practices in terms of containment and immediate clean-up would be required to assess to which extent remediation is likely to be required in the future as a result of current use of PFAS-based fire-fighting foams; and
- Therefore, realistically avoided remediation costs are more likely in the order of magnitude of hundreds of millions of Euros (assuming tens of sites requiring remediation at tens of millions

of Euros per site) to billions of Euros (assuming hundreds of sites requiring remediation at tens of millions of Euros per site).

Clean-up

In addition to remediation which is driven by long-term accumulated contamination from historical releases, releases to the environment in the short-term require "clean-up" (as defined by Task 4 of the DG ENV study, see Section 0). According to the stakeholder consultation, there is local or national-level regulation governing the containment or prevention of release of fire-fighting foam or firewater runoff to the environment[115]. One exception that has been identified is fire-fighting activities in close vicinity to open water bodies (sea, lake), where it is very difficult to recover fire-fighting water runoff discharged into the sea or lake. In the case of the lake, this could lead to remediation being required. This would relate to very specific sites in specific locations, so it would not be appropriate to estimate 'typical' remediation or clean-up costs. In the case of the sea (particularly relevant for marine and offshore applications), remediation or clean-up would likely not be feasible, which raises particular concerns over the environmental impact of using PFAS-based fire-fighting foams in these applications. In all other applications, it is assumed that in most cases, the majority of fire-water run-off is contained and sent for treatment. Treatment costs for run-off can vary depending on the fire-fighting foam used:

- Several stakeholders that have transitioned to fluorine-free foam reported that when fluorine-free foam was used, run-off was sent to water treatment, either though the normal sewer system to the municipal WWTPs; directly to on-site waste water treatment; to other biological/chemical/mechanical treatment plants; or even drained directly to sea. One stakeholder reported that all PFAS-containing run off must be treated as a regulated waste which they do using high-temperature incineration;
- Stakeholders did not provide information on the cost of waste water treatment. These can vary significantly, depending on the contamination of the run-off from the flammable liquid itself, the soot and other contaminants from the fire site. For instance, UNECE 2017[116] reports a cost of €1 million for disposal of 2,000 m^3 of firewater contaminated with chemicals in a sewage treatment plant and several chemicals waste disposal facilities, resulting from a fire in a factory in Germany in 2005. This is equivalent to €0.5 per litre, or €0.64 per litre in 2019 prices[117]. Typical costs for regular municipal waste water treatment are much lower, for instance reported in the range of €0.0002 to €0.0005 per litre by Pajares et al. 2019[118] for various municipalities in Southern Europe. Hence, treatment costs for run-off for fluorine-free foam are likely between €0.0002 per litre and around €0.64 per litre. €0.3 per litre is assumed as an average for the purpose of the approximate estimation below;
- Assuming that PFAS-containing run-off has to be incinerated, and assuming similar incineration costs as reported for the disposal of fire-fighting foams (see Section "I. Costs of disposal"), the costs for treatment of PFAS-containing fire-water run-off could be around €1 per litre (range

[115] This was confirmed by stakeholders at least for England/Wales (The Environmental Permitting (England and Wales) Regulations 2010 (EPR 2010)), Sweden (local authority requirements for applications for new operation licenses), France (no details provided), Netherlands (no details provided), Germany ("Löschwasser-Rückhalte-Richtlinie" and the more detailed Bavarian "Guideline foam" which is legally binding in Bavaria and but also applied elsewhere).

[116] https://www.unece.org/fileadmin/DAM/env/documents/2017/TEIA/JEG_MTGS/UNECE_Safety_Guidelines_and_Good_Practices_for_Fire-water_Retention_14_Nov_2017_clean.pdf

[117] 2005 value converted to 2019 prices using Eurostat: HICP (2015 = 100) - annual data (average index and rate of change) (prc_hicp_aind).

[118] Moral Pajares, E., Gallego Valero, L., & Román Sánchez, I. M. (2019). Cost of urban wastewater treatment and ecotaxes: Evidence from municipalities in southern Europe. *Water*, *11*(3), 423.

€0.3 to €11 per litre). Hence, treatment costs for run-off of fluorine-free foams could be around €0.7 per litre (range ca €0-€11) lower compared to PFAS-based foams.[119]; and

- Data on the total amount of fire-water run-off containing fire-fighting foam per year in the EU was not available, but for illustration an example of costs per incident can be calculated. UNECE 2017[120] reports five major fire-incidents in which volumes of fire-water used ranged between 2,200 and 38,000 m^3. For incidents of this size, the difference in run-off treatment cost would be around €1.5-27 million (range €0-418 million) per incident.[121].

In cases where fire-water run-off is not contained and further clean-up is possible (i.e. run-off was not discharged to sea), there may be savings from using fluorine-free foams in terms of reduced clean-up costs:

- When PFAS-based foam is used and contamination of the soil and water occurs then extremely persistent chemicals are involved, which is not necessarily the case with fluorine-free foams. Stakeholders suggested in the consultation that clean-up and complex treatment is not always necessary after the use of fluorine-free foams. This could lead to potential cost savings in some cases;
- However, Section 0 determined that clean-up is driven to a large degree by the flammable liquid itself, the soot, water and "dirt" in general terms that contribute to the fire-fighting water runoff, rather than the fire-fighting foams. Therefore, a significant difference in clean-up costs between the different types of foam used is difficult to estimate, because the incremental costs of addressing PFAS contamination is difficult to separate from the wider clean-up costs; and
- Clean-up costs are generally expected to be lower than remediation costs. Based on the estimates of remediation cost per site presented above, as a worst case scenario, clean-up costs can be expected to be a few hundred thousand to a few million Euros per incident. In the absence of more specific data, for illustration of the potential order of magnitude of savings: Assuming several tens of incidents per year using PFAS-based foams where clean-up is required and could be avoided if fluorine-free foams were used, the savings would be in the order of several millions to several tens of millions of Euros.

h. Availability of alternatives.

This section discusses the supply-demand balance associated with a restriction on PFAS firefighting foams under Scenario 1 and 2. Both scenarios will require a transition to alternatives – the difference is the speed at which this will be necessary. Scenario 1 will result in a slower increase in demand as stocks are used in training and or incidents (or reach the end of their useful life) and are then replaced with new alternatives.

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[119] Calculated as:

- Central estimate: €1/l cost of incineration of PFAS-based foams minus €0.3/l cost of waste water treatment for fluorine-free alternatives = €0.7/l cost saving;
- Low estimate: Waste water treatment could in some cases be more expensive (up to €0.64/l) than incineration (from €0.3/l). In these cases it is assumed that the less expensive option would be chosen and there would not be a saving of using fluorine-free foams compared to PFAS-based foams; and
- High estimate: The maximum possible difference is in case of the upper end of the range of incineration costs for PFAS-based foams (€11/l) minus the lower end of the range of waste water treatment costs for fluorine-free alternatives (€0.0002/l) ≈ €11/l cost saving.

[120] https://www.unece.org/fileadmin/DAM/env/documents/2017/TEIA/JEG_MTGS/UNECE_Safety_Guidelines_and_Good_Practices_for_Fire-water_Retention_14_Nov_2017_clean.pdf

[121] Calculated as: 2,200 m^3 volume of fire-water run-off * €0.7/l treatment cost difference= €1.54 million.38,000 m^3 volume of fire-water run-off * €0.7/l treatment cost difference= €26.6 million. These figures are rounded to two significant figures. For the wider range, instead of €0.7l treatment cost difference, €0/l (lower) and €11/l (higher) have been applied.

Scenario 2 will result a more sudden increase in demand as the whole market disposes of and replaces their existing stocks – potentially over a short timescale - and then require replacement stock, each year.

In addition, and over and above the replacement demand, it can be assumed both scenarios will result in an increased short-term demand for testing; again the increase in demand would be greater in scenario 2 given the accelerated transition.

The economic and logistical challenges of managing the transition – avoiding contamination in storage tanks and the requirements for disposal, for example – are discussed elsewhere in the SEA. Information on the specific shortlisted substances in the analysis of alternatives is summarised below – quantitative information is limited. These substances are however, illustrative and a subset of a larger range of alternative foams that are commercially available and currently in use.

Table 8.10 Availability of alternatives – summary

Alternative	Produced in the EU	Currently commercially available	Information on production volumes
Respondol ARF 3-6%	Unknown	Yes	Not available. Stakeholders have indicated that they would not have a problem meeting increased demand in general terms.
RE-healing foam RF3X6 ATC	Yes	Yes	As above.
RE-healing foam RF1-1%	Yes	Yes	As above.
Moussol FF 3X6 (F-15)	Yes	Yes	As above.
FoamMousse 3% F-15	Yes	Yes	As above.
Epocol Premium	Yes	Yes	700 tonnes (production and import), 500 sold in EU.
Orchidex BlueFoam (3x3)	Yes	Yes	Stakeholder (not manufacturer estimates at c.800 t/yr)

Source: Market assessment, desktop research and stakeholder consultation exercise.

Stakeholder consultation has provided limited information on production and use volumes of specific foams but the market assessment indicated current supply is in the region of 7,000 to 9,000 tonnes. Anecdotal information from stakeholder consultation notes that "adequate" supply exists and no consultees noted that they had experienced supply constraints in any application. Further discussions with three suppliers indicated current excess production capacity alongside additional capacity for emergencies (not quantified). The consultees noted no constraints with raw material supply.

Production and sales data on one shortlisted product, Epocol, was provided as noted above in Table 8.10. This data indicated total production and import capacity of 700tonnes, with sales of 500tonnes. Quantitative information was provided on a small number of other specific products. These are not listed above but were stated by consultees as appropriate for use in several applications, including municipal firefighting, storage facilities and marine applications. For these, total volumes produced and imported into the EU totalled a further 550 tonnes, with sales of 380 tonnes. Qualitative information on the availability alternatives was provided via stakeholder consultation on a wider range of products. A total of 22 were stated as being produced in the EU and all of these were commercially available (either in the EU, globally or both). Note that the substance identification and market assessment identified a larger number of products – in the order of 160 - but more detailed information on only a subset of these was obtained via the consultation and the assessment has focused on products for which stakeholders have indicated actual use is taking place.

Using data from the market assessment, Table 8.11 provides a quantitative summary of available information. First, the table provides a summary of existing EU demand for PFAS based firefighting foams.

This has been split by application, based on Eurofeu survey information. Overall, this indicates current PFAS based foam demand in in the region of 18,000 tonnes per year[122], with the largest use in the chemical and petrochemical sector. The second, central, column provides an overview of the volumes of alternative foams that may be expected after a restriction is imposed. This takes into account that additional volumes may be required in some applications.

As in the economic feasibility section above, the analysis has been undertaken assuming no change in the volumes required (central estimate), and a 50% and up to 100% increase, respectively in the volume of foam required in all applications. It is not considered likely that this increase will be required uniformly across all applications; indeed the stakeholder consultation indicated that many users experienced no overall increase in the volumes required. Finally, the existing demand – again based on Eurofeu survey data – Is presented on current fluorine-free foam supply in the EU. The disaggregation of demand by sector is based on the proportions specified in the Eurofeu survey. For both PFAS-based and fluorine-free foams, sector specific volumes are subject to greater uncertainty than the overall totals.

Table 8.11 "Top down" assessment – annual demand and supply of PFAS and Fluorine free FFF

Sector of use	Current PFAS foam volumes (t/yr) Central (L-H range (000's))	Existing F- free volumes (t/yr)	Expected future additional demand for F-Free foams Central (L-H range 000's)
Chemical/Petrochemical	11,000 (8-12)	2,000 – 2,600	11,000 (8-24)
Municipal Fire Brigades	2,000 (2-3)	3,100-4,000	2,000 (2-6)
Marine Applications	2,000 (2-2)	1,100-1,400	2,000 (2-4)
Airports	2,000 (1-2)	500-600	2,000 (1-4)
Military	2,000 (1-2)	100-200	2,000 (1-4)
Ready for use products	<500	c.100	<500
Total	18,000 (14 – 20)	7,000 – 9,000	18,000 (14 - 40)

Source: Market assessment, desktop research and stakeholder consultation exercise.

The above information indicates that, for all uses, the volumes of fluorine free alternatives would need to increase to meet the replacement demand as users switch from PFAS containing foams under a restriction. Overall, the increase is likely to be in the order of 18,000 tonnes (i.e. sales of 18,000 tonnes of PFAS foam ceases, to be replaced by 18,000 of fluorine free foams), but potentially up to 40,000 tonnes, per year.

Stakeholders indicated that spare foam production capacity exists and that users had not experienced a shortfall in supply. However, Scenario 2 may result in a more sudden and potentially significantly larger demand for fluorine free foams, as existing stocks would need to be disposed of and replaced. As noted above, this could be in the region of between 210,000 tonnes and up to a theoretical maximum of 870,000 tonnes of foam. This heightens the risk of a shortfall in supply, - depending on the timescales of any restriction.

Overall, the available evidence clearly indicates a range of alternative foams are currently available on a commercial basis. Moreover, data obtained from stakeholder consultation suggests that in purely

[122] Note that the sum of the sectors is not equal to the total due to rounding.

quantitative terms existing production capacities can accommodate some increase in demand. For Scenario 1, it has not been possible, despite further consultation attempts, to obtain quantitative information on the supply of specific products used in all applications, so whilst it is possible, that a shortfall may arise for a specific market segment, the available evidence does not suggest this would be likely. For Scenario 2 a much greater quantity of alternatives would be needed to replace existing stocks, with the potential for a shortfall in supply.

As the largest single use, and with comparatively low current fluorine free sales volumes, the risks of supply constraints may be greater in the chemicals and petrochemical sectors (because this is the sector with greatest use) and in Scenario 2 (because this would require greater volumes to be replaced in the short term). It follows that appropriate transition periods would further ease this risk.

Whilst there would be costs associated with increasing supply, the market assessment and economic feasibility sections noted above indicated that, on average, the costs for fluorine free foam, on a unit basis, are comparable to or less than those for PFAS based foams. It appears reasonable that manufacturers could continue to increase supply without significant costs having to be passed to downstream users. The range of suppliers and the number of fluorine free products that currently exist on the market would also serve to limit scope for significant price increases.

i. Other impacts

Other impacts briefly considered in this section include the potential for impacts on international trade and employment and economic competitiveness.

Under Scenario 1, PFAS-containing foams in stock will still be able to be used and therefore the demand for replacement with alternatives will be more gradual. It is therefore unlikely that there will be any substantial impacts on competitiveness, trade and employment.

Under Scenario 2, there will be a more sudden and larger increase in EU demand for PFAS-free alternative fire-fighting foams and decrease in demand for PFAS-containing fire-fighting foams (again depending on transition period). Imports of PFAS-containing fire-fighting foams into the EU will therefore decrease and manufacturers (both global and EU) of PFAS-containing foams will see a decrease in EU demand. Whilst effects would be mitigated by the fact that at least some manufactures in the EU are involved in both PFAS and fluorine free foam manufacturing, a potential shortfall in supply – driven by a one off need for stock replacement - may impact imports of fluorine free foam from outside the EU. ,

Regarding employment, there is no information available on the number of people employed in manufacturing of PFAS-containing fire-fighting foam or manufacturing fluorine-free fire-fighting foam. Overall effects would be neutral or positive, depending on the net effect on volume,

Overall, there are unlikely to be any significant macroeconomic impacts from the result of Scenario 1, but with some – albeit temporary risk of increase EU imports under Scenario 2.

j. Emissions from disposal of legacy foams

During the process of disposing of PFAS-containing legacy foams, emissions occur from several sources. In Scenario 1, it is expected that a low quantity of legacy foam will be required for disposal. This low quantity will relate to 'transitional wastage' which occurs when a user has some remaining PFAS-containing fire-fighting foam in existing equipment, yet their stock of PFAS-containing firefighting foam has depleted to zero. PFAS-containing and PFAS-free fire-fighting foam cannot be combined in the same system. The low level of PFAS-containing foam left in the container will need to be disposed of. The quantity of foam required for disposal under Scenario 1 cannot be accurately quantified as 'transitional wastage' will likely vary across industries and appliances.

In Scenario 2, all existing stocks of PFAS-containing foam will need to be disposed of. This section first discusses the disposal options and identifies the potential emissions associated with these disposal options. The quantity of emissions is then estimated and the impact of these emissions on health and the environment are discussed. Emissions considered relate to both the potential for remaining PFAS compounds as well as the by-products created from disposal. The analysis focusses on the disposal of unused PFAS-containing foams, rather than the disposal of used PFAS-containing foams. Little data and information was obtained from stakeholder consultation, therefore much of this section is based on desktop research.

- **High-temperature incineration** would appear the most likely disposal option for PFAS-containing legacy foams[123];
- **Existing incineration disposal methods used apply a range of temperatures from around 400-6000°C[124].** The literature also indicates that CF_4 requires temperatures above 1,400°C to decompose and that CF_4 is the most difficult fluorinated organic compound to decompose[125];
- The effectiveness of PFAS compounds to be destroyed by incineration and "the tendency for formation of fluorinated or mixed halogenated organic by-products is not well understood"[126];
- **The incomplete destruction of PFAS compounds may result in smaller PFAS or products of incomplete combustion being formed**[127]. These products may not yet have been researched and therefore have the potential to be chemicals of concern[128];
- The **complete combustion of PFOS/PFAS will result in CO_2, H_2O and HF**[129] and the incineration of PFAS at temperatures of at least 1,100°C, usually degrade PFAS to carbon dioxide and hydrogen fluoride[130]. It has not yet been determined what is produced when PFAS is incinerated at temperatures lower than 1,100°C[131];
- **Emissions (greenhouse gases and air pollutants) from creating high temperatures for incineration:** There are emissions associated with the procurement and delivery of fuel and with incinerator operation (e.g. greenhouse gases and air pollutants such as particulate matter from the combustion of fuels). Associated emissions have not been analysed and it is assumed that the incinerators would continue to operate at the same temperatures regardless of the type of waste they process. Such emissions were not highlighted by stakeholders in the consultation;
- **Leakage during storage and transportation:** Incineration processes are typically provided off-site and foams will need to be stored and transported to incineration facilities for disposal or waste equipment to be installed on-site[132]. During the storage and transportation of PFAS-containing foam it may be possible for spillages or leakages to occur, resulting in environmental emissions. There has not been enough information identified during desktop based research or provided from stakeholder consultation to accurately quantify these emissions; and

[123] Derived from stakeholder consultation responses concerning PFAS disposal methods. Note that WWT was also reported as a disposal method, but a judgement was made that these disposal techniques relate to used PFAS-containing firefighting foam rather than unused foam.
[124] Obtained from stakeholder consultation.
[125] https://www.epa.gov/sites/production/files/2019-09/documents/technical_brief_pfas_incineration_ioaa_approved_final_july_2019.pdf
[126] https://www.epa.gov/sites/production/files/2019-09/documents/technical_brief_pfas_incineration_ioaa_approved_final_july_2019.pdf
[127] https://www.epa.gov/sites/production/files/2019-09/documents/technical_brief_pfas_incineration_ioaa_approved_final_july_2019.pdf
[128] https://www.epa.gov/sites/production/files/2019-09/documents/technical_brief_pfas_incineration_ioaa_approved_final_july_2019.pdf
[129] https://www.diva-portal.org/smash/get/diva2:1155115/FULLTEXT01.pdf
[130] UNEP, 2012 in: https://www.kemi.se/global/rapporter/2016/report-11-16-strategy-for-reducing-the-use-of-higly-fluorinated-substances-pfas.pdf
[131] https://www.kemi.se/global/rapporter/2016/report-11-16-strategy-for-reducing-the-use-of-higly-fluorinated-substances-pfas.pdf
[132] https://www.serdp-estcp.org/content/download/48955/466822/file/ER18-1593%20Final%20Report.pdf

- **Direct emissions (greenhouse gases and air pollutants) from transportation:** Where foams are stored and transported to incineration facilities, direct emissions of carbon and other pollutants (particulate matter, nitrogen oxides, etc.) from vehicles will also occur. Desktop based research revealed a lack of available data regarding the geographical position of PFAS-containing fire-fighting foam manufacturers and users in relation to incineration facilities and little to no information was obtained from stakeholder consultation. It is therefore unsuitable to accurately quantify emissions associated with foam transportation.

Overall, PFAS emissions from incineration are not well studied[133] and therefore, there is the potential for incineration to be hazardous[134]. Further research is needed to identify and quantify the emissions produced from the incineration of PFAS, as well as greater research undertaken to understand the thermal properties of PFAS.

k. Technical feasibility / availability of disposal options (legacy foams)

This section assesses the potential for existing disposal options to feasibly dispose of legacy foams in Scenario 2. The disposal of legacy foams is not considered in Scenario 1, as existing stocks will still be able to be used until they run out. With Scenario 2, a sudden increase in the short-term demand for disposal will likely occur as the whole market will dispose of their stocks to enable replacement. The level of demand for disposal will depend on what transition period is established (yet to be determined). In order to meet the demand, existing disposal options must have the capacity to process the quantities of foam to be sent for disposal. This subsection identifies the disposal options available and discusses their capacity to process and dispose of PFAS-containing foams given a sudden increase.

There are several incineration methods available. One stakeholder reported two specific and different incineration methods: cement kiln and plasma arc furnace. A cement kiln operating from around 400°C has a retention time of 20 minutes. A cement kiln operating between around 850-1800°C has a residence 16-24 seconds (with a minimum of 2 seconds). Estimated costs of PFAS disposal by cement kiln incineration are around €2/l. Another stakeholder who has transitioned to fluorine-free foams also reported that their stocks of PFAS-based foams were incinerated in a cement kiln, but reported costs around €1 per litre. Plasma arc furnace conditions can reach 6000°C and have an estimated processing cost of €11/l.[135] It would therefore appear that costs are higher for incinerators operating at higher temperatures and there is a **potential trade-off between the cost of incineration, effectiveness of PFAS destruction and time**, due to higher temperatures being more likely to completely destroy the PFAS.

With the sudden increase in short-term demand for incineration, existing disposal methods would need to be sufficient to process the volume of legacy PFAS foams required to be disposed of. Where capacity is insufficient, the storage of the foam will likely be required. The following assumptions are made to derive the capacity for existing incinerators to process PFAS-containing foam and the time it would take to complete this (not taking into account transportation times):

- The literature indicates that there are **808 incineration facilities across EU28**[136]. These include high temperature hazardous waste incinerators as well as municipal waste incinerators that probably operate at lower temperatures. However, according to the Industrial Emissions Directive[137] Article 50, all incinerators need to be designed, equipped, built and operated so that a temperature of at least 850°C is achieved for at least two seconds. It is therefore assumed that all 808 incinerators are able to operate at least at 850°C. However, as discussed in

[133] http://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf
[134] https://www.epa.gov/sites/production/files/2019-09/documents/technical_brief_pfas_incineration_ioaa_approved_final_july_2019.pdf
[135] Obtained from stakeholder consultation. Note that it is not clear whether this relates to foam concentrate or other foam types being processed.
[136] The Cost of Inaction - http://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf
[137] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control)

the previous sub-section, at least 1,100°C (or for some PFAS even at least 1,400°C) are required to degrade PFAS to carbon dioxide and hydrogen fluoride and it has not yet been determined what is produced when PFAS is incinerated at lower temperatures. Data was not available to determine the share of EU incineration facilities that achieves 1,100-1,400°C;

- The **amount of PFAS-containing legacy foam for disposal is between 210,000 tonnes and 435,000 tonnes (average 322,500 tonnes)**;
- Information obtained from stakeholder consultation indicates that an incinerator operating at around 850-1800°C can process one tonne of foam per hour and an incinerator operating at around 6000°C has a throughput of around 25l per hour. It is assumed that 1kg = 1l; and
- It is also assumed that incinerators continuously operate with the same processing capacity and at the same temperature, 24 hours a day.

Based on the above assumptions, the tables below provide estimates of the time it will take incinerators to dispose of fire-fighting foams based on 808 incinerators having a processing capacity of 25l per hour or one tonne per hour. As discussed above, to ensure adequate destruction of PFAS, it would appear to be preferable to dispose of PFAS-containing firefighting foams at incinerators with higher temperatures (at least 1,100-1,400°C). This will therefore reduce the capacity available and increase the time period required for disposal.

Table 8.12 Processing time based on existing incinerator capacity processing 25l per hour.

Foam to be disposed of (tonnes)	Time for foam to be disposed of (hours)	Time for foam to be disposed of (days)
210,000 (low)	10,400	400
322,500 (average)	16,000	700
435,000 (high)	21,500	900

Note that all cost values are assumed to represent the cost of disposal of unused PFAS-containing fire-fighting foams and not used PFAS-containing firefighting foam. Source: market assessment, desktop research and stakeholder consultation. Values have been rounded.

Table 8.13 Processing time based on existing incinerator capacity processing one tonne per hour.

Foam to be disposed of (tonnes)	Time for foam to be disposed of (hours)	Time for foam to be disposed of (days)
210,000 (low)	260	10
322,500 (average)	400	20
435,000 (high)	540	20

Note that all cost values are assumed to represent the cost of disposal of unused PFAS-containing fire-fighting foams and not used PFAS-containing firefighting foam. Source: market assessment, desktop research and stakeholder consultation. Values have been rounded.

Responses from the stakeholder consultation indicate that there is sufficient capacity for disposal of PFAS-containing foams. One stakeholder reports that there is sufficient capacity for disposal, but that getting high-temperature incineration capacities is becoming more difficult. Another stakeholder also reports that sufficient capacity for disposal by incineration is not guaranteed. Capacity for disposal is also likely to depend on the transition period chosen (yet to be determined) and was mentioned in the stakeholder consultation. If the transition period is short, there is the potential for demand for disposal facilities to outstrip supply. A longer transition period is more likely to result in the demand and the quantities sent for disposal being spread over a greater time period. Alternatively, a sector by sector introduction of Scenario 2 could be introduced to also spread the demand for disposal over time and avoid destruction capacity being exceeded[138]. Note that it is not clear whether stakeholder responses relate to used foams or whether responses relate to the sufficient capacity for the disposal of legacy foams if Scenario 2 were to occur. Additionally, the geographical locations of incinerators, the feasibility of storing and transporting PFAS to destruction facilities as well as the availability of transportation vehicles and labour has not been evaluated due to lack of information from both desktop-based research and stakeholder consultation. Further, the knock -on effects on other sectors requiring use of incineration facilities have not been considered.

l. Costs of disposal (of legacy foams)

This section discusses the costs associated with the disposal of legacy PFAS-containing firefighting foams under Scenario 2. Costs occur from the disposal process itself, as well as from transportation to disposal facilities and the storage of PFAS-foams. Costs of disposal are not considered to be incurred in Scenario 1, unless 'transitional wastage' occurs, where the disposal of some PFAS-containing foam must happen to enable a switch to an alternative. Information and data is unavailable to accurately quantify the amount of 'transitional wastage'. This subsection therefore focuses on costs associated with Scenario 2. First, the direct cost of incineration is calculated based on the stocks required for disposal. Costs associated with transportation to incinerators, labour costs and the potential costs of storage are qualitatively discussed.

Incineration costs

Incineration costs refer to the direct cost charged for the incineration of PFAS waste. Obtained from stakeholder consultation, the costs of disposal by incineration at temperatures between 850-1800°C are between around €0.3-1.5 per litre[139]. Two stakeholders who have transitioned to fluorine-free foams both reported that their stocks of PFAS-based foams have been incinerated at costs of around €1 per litre. For incineration at a higher temperature of around 6000°C, a cost of around €11/l is estimated. It is therefore considered more costly to dispose of PFAS-contained foams at incinerators with higher temperatures. Table 8.14 provides estimates of the cost for the disposal based on the total amount of PFAS-containing fire-fighting foam to be disposed of at 322,500 tonnes (average), 210,000 tonnes (low) and 435,000 tonnes (high).

Table 8.14 Estimated costs of disposal

Foam to be disposed of (tonnes) Best estimate	Cost of disposal (€/l): L-M-H	€0.3 (low)	€1.0 (best estimate)	€11 (high)
210,000 (low)		63m	210m	2,310m
322,500 (average)		97m	323m	3,547m
435,000 (high)		130m	435m	4,785m

Note that all cost values are assumed to represent the cost of disposal of unused PFAS-containing fire-fighting foams and not used PFAS-containing firefighting foam. Source: market assessment, desktop research and stakeholder consultation. Values have been rounded.

[138] Obtained from stakeholder consultation.

[139] Note that it is not clear overall whether stakeholder consultation responses refer to foam concentrate or another measure of foam. One stakeholder explicitly reports disposal costs at €1 to €1.5/m^3 of foam concentrate for high temperature incineration (1,100-1,200°C). €1/l is considered a middle value due to stakeholder consultation reporting this is the cost of disposing of old foam. Not all costs were provided in euros and conversion rates have been used. It has also been assumed that 1kg = 1l.

However, it should be noted that at least part of the PFAS-containing fire-fighting foams would reach their expiry date without being used and therefore be incinerated in any case, just at a later date. For these foams, a restriction on the use of PFAS-based fire-fighting foams would only bring their incineration forward and therefore the incineration cost of fire-fighting foams that would have expired is not additional to the baseline, i.e. not a cost of the restriction. As discussed earlier[140], it is not known what share of fire-fighting foams is used before its expiry date, but if reported usage rates of 15-20% per annum of existing stocks is an average across all sectors of use, there will be some installations with potentially far lower usage rates annually that will likely have some foams that reach expiry before use. Hence, an unknown share of the costs are not additional to the baseline and the costs presented in Table 8.14 should be considered a higher boundary of the actual cost of the restriction in terms of the costs of disposal of legacy foams.

Transportation costs

Stakeholder responses did not identify transportation costs in relation to the costs of disposal. However, it is possible that transportation costs may occur where PFAS-containing fire-fighting foams need to be transported to incinerators off-site. These may include the costs associated with vehicle operation such as fuel costs (which will likely vary across the EU and be dependent on fuel prices) and distance covered between the pick-up point for PFAS and the site for incineration. Desktop based research reveals that Greece has the highest number of incinerators (132), followed by Belgium (100), Italy (100), Germany (93), the UK (87) and Poland (85)[141]. However, without detailed information concerning the location of PFAS foam users and manufacturers, it is not feasible to derive accurate transportation costs associated with disposal.

Storage costs

Stakeholder responses referred to storage costs within the context of requiring multiple foams to be stocked, particularly during a transition to PFAS-free foam, rather than within the context of disposal. This cost could be mitigated through phased transition. These costs have not been quantified here.

Labour costs

Labour costs may be incurred during the collection of PFAS-containing firefighting foams as well as during their transportation to incineration facilities. Stakeholder consultation did not provide any responses relating to labour costs for the disposal of PFAS and these would likely form part of the overall incineration costs.

8.3 Conclusions

Table 8.15 below summarises the results for all impacts discussed in this chapter.

[140] In the emission assessment in Task 3 (Section 5) and the SEA section on savings from adoption of fluorine-free foams ("e. Impacts associated with the economic feasibility of alternatives").
[141] http://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf

Table 8.15 Summary of socio-economic considerations for the main expected impacts of potential regulatory management options

Impacts	Economic	Social	Health/Environmental	Wider economic implications
a. Cleaning of equipment	Costs vary by equipment, process and achievable concentration. According to one estimate up to €12,300 per appliance achieving PFAS levels below 1000ppt (1/3 of appliances below 70ppt), which could imply EU total costs in the order of €1 billion, but established simpler methods have also been reported (cost not quantified). The replacement of equipment is likely to be required in some cases, depending on the threshold chosen. Replacement costs for extinguishers alone estimated at €15-450 million (EU total). Replacement cost for other equipment not quantified.	None identified.	Trade-off between cost for cleaning/replacement and threshold concentrations for remaining PFAS contamination. Replaced equipment and media (e.g. water) used in cleaning process must be disposed of or treated safely to avoid worker or environmental exposure.	None identified.
b. Other risk management options	None identified.	None identified.	None identified.	None identified.
c. Fire safety –impacts of technical performance of alternatives	It is not expected that any damages would be caused, see Health/Environmental. This is however still uncertain for large atmospheric storage tanks.	None identified.	AoA concluded alternatives are technically feasible and successful transitions have been shown in most applications. Further testing required to confirm whether this covers also large atmospheric storage tanks (LAST), the application of most concern. Speed of fire suppression may be slower and application of foams may be less flexible and less easy to use, according to some stakeholders. This has not been shown to be generally the case and resulting health/safety impacts could not be quantified.	None identified.

Impacts	Economic	Social	Health/Environmental	Wider economic implications
d. Use patterns to achieve comparable/acceptable performance using alternatives	Between no change in volume and up to a maximum of 100% additional foam required (additional cost considered in e. below). In sprinkler applications, special sprinkler nozzles have to be installed (cost not quantified). More than one foam may need to be stocked by users to cover different flammable liquids, with logistical, training and safety implications for users.	None identified.	More than one foam may need to be stocked by users to cover different flammable liquids, with logistical, training and safety implications for users.	None identified.
e. Economic feasibility of alternatives	For both Scenarios: Most likely there is no significant price difference (per litre) between PFAS-based foams and alternatives, but up to 100% more volume may be required (central estimate 50%) to achieve desired performance. This would lead to costs around €27m per year (EU total, central estimate) Potential additional economic costs for transitioning may include testing costs (not quantified), storage costs, (not quantified) costs from technical changes to delivery systems (e.g. €5-€200 pre nozzle or around €2,700 for a mobile foam unit, but generally conceived as manageable), and regulatory approvals (not quantified). Potential savings may include lower foam disposal costs at expiry date (likely order of magnitude €100,000 to several million) lower fire-water disposal costs (covered under g. Remediation and clean-up), avoided cross contamination of waste, reduced regulatory requirements and reduced PPE requirements (not quantified). Additionally for Scenario 2: Costs for existing stock of PFAS-based foams (estimated 210,000-435,000 tonnes) will have to be written off (and new stocks purchased causing an additional cost (central estimate €1.0bn) over the baseline.	None identified.	None identified.	None identified.

Impacts	Economic	Social	Health/Environmental	Wider economic implications
f. Environmental/health – impacts of alternatives	None identified.	None identified.	Based on the assessed substances, non-fluorinated alternatives are of lower environmental concern, primarily due to greater biodegradation. A quantitative comparison of risk under each scenario was not possible with the available data.	None identified.
g. Remediation and clean-up	Potential risk of PFAS contamination could be eliminated, which could save up to around €100 million remediation costs per site. Depending on the extent of containment and immediate clean-up, the number of relevant sites is likely low, but overall savings could still be in the order of magnitude of €100s of millions to € billions More information on the total number of sites and real-world implementation and effectiveness of best practices would be required to be more precise. Treatment of fire-water run-off and short-term clean-up largely driven by other contents of fire-water run-off and cost saving estimates are very uncertain. Run-off treatment savings could be €0.7 per litre (range ca €0-€11) or €0 to €10s of millions per incident, and clean-up cost savings up to €10s of millions in total.	None identified.	Potential trade-off between remediation cost and remaining PFAS contamination.	None identified.
h. Availability of alternatives	Range of alternatives and capacity to increase production likely available. No significant supply shortages or additional costs expected in Scenario 1. Scenario 2 may result in a more sudden and potentially significantly larger demand for fluorine-free foams to replace existing stocks of PFAS-based foam. This heightens the risk of a shortfall in supply, - depending on the timescales of any restriction. As the largest single use, and with comparatively low current fluorine free sales volumes, the risks of supply constraints may be greater in the chemicals and petrochemical sectors.	None identified.	None expected in Scenario 1. The risk of supply supply-shortages is higher in Scenario 2 (depending on timescales of a restriction), which could potentially lead to additional fire-safety risks.	None identified.

Impacts	Economic	Social	Health/Environmental	Wider economic implications
i. Other impacts	None identified.	There is potential for employment impacts but significant impact is deemed unlikely and any net effect at the EU level would be negligible.	None identified.	Under Scenario 2, a potential shortfall in supply – driven by a one off need for stock replacement - may impact imports of fluorine free foam from outside the EU. Overall, there are unlikely to be any significant macroeconomic impacts from the result of either Scenario 1 or Scenario 2.
j. Emissions from disposal of legacy foams	None identified.	None identified.	High temperature incineration has been identified as main disposal method. There are potential hazards (emissions of hydrogen fluoride and PFAS), but further research is needed to identify and quantify the emissions produced from the incineration of PFAS.	None identified.
k. Technical feasibility / availability of disposal options	If the transition period is short, there is the demand for disposal facilities may outstrip supply, leading to potential additional costs and potential for emissions.	None identified.	Trade-off between temperature of incineration (with lower capacity and higher costs) and effectiveness of PFAS destruction. If the transition period is short, there is the demand for disposal facilities may outstrip supply, leading to potential additional costs and potential for emissions.	None identified.
l. Costs of disposal	Total EU costs estimated at up to €320 million (range up to €60m-€4.8bn) depending on the method used (with implications on effectiveness, see Health/Environmental) and the share of foams that would have reached expiry date without use. Additional transport, storage and labour costs may be incurred (not quantified).	None identified.	Trade-off between temperature of incineration (with lower capacity and higher costs) and effectiveness of PFAS destruction.	None identified.

Scenario 1: Restriction on the placing on the market of PFAS-containing fire-fighting foams

Scenario 1 would allow users to continue using their stocks of foams, but once they are depleted, users would be forced to switch to alternative (fluorine-free) foams. The impacts that have been identified as most significant are:

- Environmental/health benefits:
  - Based on the assessed substances, non-fluorinated alternatives are likely to be of lower environmental concern, primarily due to biodegradation. The environmental and health benefit of the restriction could not be quantified but is expected to be significant; and
  - The annual health-impact in the EEA of exposure to PFAS (from all uses of PFAS, not only fire-fighting foams) has been estimated at €52–84 billion[142]. It is unclear what share of that is due to their use in fire-fighting foams, but for illustration the PFOA REACH restriction report estimated that fire-fighting foams account for about 2-4% of emissions of PFOA-related substances (a subset of PFAS).[143]
- Cost of transition to using fluorine-free alternatives:
  - As users' stock of PFAS-based foams deplete, they would need to purchase alternative foams. While the cost per litre of the alternatives is likely similar, higher volumes may be required to achieve the desired performance, which has been estimated to incur additional costs (compared to the baseline) of around €27m per year in the EU. The cost would increase gradually as legacy foam stocks are replaced and the €27m per year would be reached once the full annual demand of fire-fighting foams is served by alternatives;
  - Before using alternative foams, equipment that was previously filled with PFAS-based foams needs to be cleaned to avoid contamination of the new foams with PFAS. Cleaning costs are difficult to generalise as they vary by the type of equipment, the cleaning process used and the concentration of remaining PFAS contamination that can be achieved (and that would be allowed). These costs, could be significant. According to one estimate costs could be up to €12,300 per appliance, which could imply EU total costs in the order of €1 billion, but established simpler methods have also been reported (cost not quantified). The replacement of equipment is likely to be required in some cases if cleaning to achieve very low residual PFAS levels (to meet a threshold) is not feasible. Replacement costs for extinguishers alone are estimated at €15-450 million (EU total). Replacement costs for other equipment could not be quantified, but are likely to be more significant than for fire extinguishers. The replaced equipment and especially the media (e.g. water) used in the cleaning process must be disposed of or treated (with further cost or environmental/health implications);
  - Potential additional economic costs for transitioning that could not be quantified as EU totals but may include testing costs, storage costs, costs from technical changes to delivery systems (e.g. €5-€200 per nozzle or around €2,700 for a mobile foam unit, but generally conceived as manageable), and regulatory approvals. More than one alternative foam may need to be stocked by users to cover different flammable liquids, leading to potential logistical and training costs; and

[142] Nordinc Council of Ministers (2019): The cost of inaction - A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Available at: http://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf

[143] 0.7-1.4 tonnes per year out of a total across all sources of 18.7-56.7 tonnes per year (see table F.1-1). ECHA (2014): Annex XV restriction report – proposal for a restriction on perfluorooctanoic acid (PFOA), PFOA salts and PFOA-related substances. Available at: https://echa.europa.eu/documents/10162/e9cddee6-3164-473d-b590-8fcf9caa50e7

- This may be partly offset by potential savings from lower fire-water disposal costs, avoided cross contamination of waste, reduced regulatory requirements and reduced PPE requirements (not quantified), and lower disposal costs for foams that have reached their expiry date, all due to the potentially lower environmental/health risk of the alternative fire-fighting foams.

- Implications of the performance of fluorine-free alternatives:
  - The analysis of alternatives concluded that alternatives are technically feasible and successful transitions have been shown in most applications. However, further testing is required to confirm whether this covers also large atmospheric storage tanks (LAST), the application of most concern around feasibility of alternatives; and
  - The speed of fire suppression may be slower and application of foams may be less flexible and less easy to use (e.g. different foams may be needed for different flammable liquids), in some cases.
- Benefits of reduced clean-up / remediation:
  - A restriction would eventually eliminate the potential risk of additional PFAS contamination, which could save up to around €100 million remediation costs per site. However, only a small share of sites using fire-fighting foams would release sufficient quantities and without adequate containment and immediate clean-up to require large scale remediation. More information on the total number of sites, real-world use of PFAS per site as well as implementation and effectiveness of best practices in terms of containment and immediate clean-up would be required to assess the extent to which remediation is likely to be required in the future as a result of current use of PFAS-based fire-fighting foams. However, as a very high level estimate for illustration, the potential order of magnitude of avoided remediation could be hundreds of millions of Euros (assuming tens of sites requiring remediation at tens of millions of Euros per site) to billions of Euros (assuming hundreds of sites requiring remediation at tens of millions of Euros per site);
  - Treatment of fire-water run-off and short-term clean-up after the use of fire-fighting foams is largely driven by other contents of the fire-water run-off, rather than the foam used, so potential savings as a result of the restriction are very uncertain, because the incremental costs of addressing PFAS contamination is difficult to separate from the wider clean-up costs:
    - In most cases, the majority of fire-water run-off is contained and sent for treatment. It has been reported that at least in some cases, run-off can be sent to waste water treatment when fluorine-free foams have been used, whereas it may have to be incinerated when PFAS-based foams are used. Specific cost data was not provided but it is estimated that the difference in treatment cost could be around €0.7 per litre (range €0-€11) or €0 to €10s of millions per incident; and
    - In cases where fire-water run-off is not contained and further clean-up is possible, there may be savings from using fluorine-free foams in terms of reduced clean-up costs, because the alternative fire-fighting foams should not introduce persistent chemicals to the run-off, as would be the case had PFAS-based foams been used[144]. In the absence of more specific data, for illustration of the potential order of magnitude of savings: Assuming several tens of incidents per year using PFAS-based foams where clean-up is required and which could be avoided if fluorine-free foams

[144] As discussed in Sections 5 and 7, fluorine-free alternatives are generally less persistent than PFAS-based foams. However, note that fluorine-free alternatives still contain some hazardous chemicals and the run-off may contain other problematic contents from other sources than the foam used.

were used, the savings would be in the order of several millions to several tens of millions of Euros per year.

- It is considered unlikely that a restriction would cause any significant macroeconomic impacts (e.g. employment, trade).

Scenario 2: Restriction on the placing on the market and the use of PFAS-based fire-fighting foams

This scenario would require the switch to alternative (fluorine-free) foams to happen immediately when the restriction comes into force (or before), and for users' stocks of PFAS-based foams to be disposed of. To avoid duplication of information, the main identified impacts are discussed relative to Scenario 1:

- Environmental/health benefits:
  - Benefits resulting from a reduction of PFAS emissions would be achieved more quickly in this scenario and therefore also achieve a higher reduction of accumulative PFAS contamination; and
  - There are potential risks (emissions of hydrogen fluoride and PFAS) from the incineration of legacy foams, but further research is needed to identify and quantify the emissions produced from the incineration of PFAS.
- Cost of disposal of legacy foams:
  - Total EU costs are estimated at up to around €320 million (range up to €60m-€4.8bn) depending on the method used and the share of foams that would have reached their expiry date without use (whose disposal is merely brought forward by the restriction, but costs not additional to the baseline). There is a trade-off between the disposal costs and the mitigation of potential environmental risks from disposal (as discussed above); and
  - Additional transport, storage and labour costs may be incurred (not quantified).
- Cost of transition to using fluorine-free alternatives (other than disposal of legacy foams):
  - The existing stock of PFAS-based foams – an estimated 210,000-435,000 tonnes – would have to be written off (considering depreciation since their purchase), and new stocks would have to be purchased, subject to replacement costs (minus the value of existing stocks already depreciated) estimated at around €1.0 billion (range -€60 million[145] to €8.3 billion);
  - In addition, as discussed for Scenario 1, purchasing alternative foams is estimated to incur additional costs (compared to the baseline) on an annual basis of around €27m per year. In Scenario 2, these costs would be incurred immediately when the restriction comes into force (or before), whereas in Scenario 1 the costs increase gradually and only reach €27m per year once all stocks are depleted. As the transition is concentrated into a shorter time, supply shortages and associated price increases of alternative foams are somewhat more likely than in Scenario 1, potentially leading to additional costs. However, significant shortages and price increases are not considered very likely in either scenario. As in Scenario 1, this would be partly off-set by savings from lower disposal cost of fluorine-free foams when they reach their expiry date, lower fire-water disposal costs, avoided cross contamination of waste, reduced regulatory requirements and reduced PPE requirements; and

[145] I.e. a potential saving of €60 million, if fluorine-free alternatives are cheaper than the PFAS-based foams they replace (possible in some cases but unlikely on average) and no additional volumes are required.

- Costs for cleaning or replacement of equipment and other transitioning costs would also in principle be similar to Scenario 1, but again they would be incurred more concentrated in a shorter time. As these are one-off costs, this would not lead to higher accumulated costs compared to Scenario 1. However, the concentration in a shorter time again poses a greater risk of supply shortages and associated price increases, potentially leading to additional costs.

- Implications of the performance of fluorine-free alternatives:
  - These are considered to be the same as for Scenario 1, i.e. no negative implications are expected in general (subject to further testing for LAST).
- Benefits of reduced clean-up / remediation:
  - The reduction of the risk of future remediation or additional/more costly clean-up would be reduced even further in this scenario, given the quicker elimination of PFAS emissions and higher reductions of accumulated PFAS contamination.
- It is considered unlikely that a restriction would cause any significant macroeconomic impacts (e.g. employment, trade).

Cost-effectiveness

Following ECHA's approach to the "Evaluation of restriction reports and applications for authorisation for PBT and vPvB substances in SEAC"[146], the cost per unit (e.g. kilogram) of emission reduced are presented in the following. It should be noted that both the socio-economic costs and the emission reduction of a potential restriction of PFAS in fire-fighting foams is associated with significant uncertainties and are presented in wide ranges or sometimes indicative orders of magnitude. Not all socio-economic impacts (costs or benefits) could be quantified and often their magnitude will depend on the specific design of the potential restriction (e.g. residual concentration limits). As a result, the cost-effectiveness will be subject to the same uncertainties and can only be calculated as an indicative order of magnitude.

Total emission reduction

Some 14,000-20,000 tonnes of PFAS-based fire-fighting foams are used annually in the EU (the best estimate used in the SEA is some 18,000 tonnes) and the market analysis suggested these contain an average concentration of fluorosurfactants of around 2-3% (average of 2.5% used as best estimate below). The emission model developed in Section 5 estimated that 26% of the two modelled example PFAS surfactants used in fire-fighting foams are released to the environment. A range was not calculated, so a 50% range around that central estimate is used below. These assumptions yield the following estimate of total annual tonnage of PFAS emissions reduced if the use of PFAS-based fire-fighting foams in the EU were to cease:

Table 8.16 Estimate of total annual PFAS emissions from fire-fighting foams

	Tonnes of foams used per year	Concentration of PFAS surfactants in foams	Share of PFAS surfactants released into the environment	Tonnes of PFAS released
Low	14,000 t	2%	13%	36 t
Best	18,000 t	2.50%	26%	117 t

146 https://echa.europa.eu/documents/10162/13580/evaluation_pbt_vpvb_substances_seac_en.pdf/af4a7207-f7ad-4ef3-ac68-685f70ab2db3

	Tonnes of foams used per year	Concentration of PFAS surfactants in foams	Share of PFAS surfactants released into the environment	Tonnes of PFAS released
High	20,000 t	3%	39%	234 t

Sources: DG ENV study tasks 2 and 3.

It should be noted that this cost-effectiveness analysis only considers the reduction of PFAS emissions. The increased emissions of alternatives resulting from a potential restriction is not considered here, but the relative hazards of the alternatives are discussed in other relevant sections of this report (in the hazards and emissions task, the AoA, the SEA and the RMOA).

Total cost of emission reduction

The main quantified costs (and benefits) of a potential restriction are listed below. Note that this list is for illustrating the approximate cost-effectiveness, but should not be understood as a total summary of costs and benefits. It should be read in conjunction with the SEA conclusions above to put these costs and benefits in context with the appropriate caveats and other unquantified impacts. In particular, benefits from avoided remediation costs have not been included here, because they constitute an environmental benefit rather than a cost of emission reduction. If these were included, they would significantly reduce the total costs (or even result in a net benefit)[147]. However, they remain an important benefit included in the SEA.

In order to compare the costs with annual emission reductions, one-off costs need to be annualised. Annualisation requires the selection of a cumulative time period over which to assess the cost-effectiveness of the restriction. Following ECHA guidance on SEA for restrictions[148], this should reflect a typical investment cycle. The typical shelf-life of fire-fighting foams of 15 years (as assumed elsewhere in this report) has been used here, although it should be noted that related equipment may have much longer investment cycles and so a longer period could be used which would reduce the annualised cost. A 4% discount rate has been applied[149]. The total of annual costs plus annualised one-off costs shows that (at least at the chosen cumulative time period, for the costs and benefits that could be quantified) the one-off costs clearly dominate the balance of overall costs and benefits.

Table 8.17 Estimate of total quantifiable cost of a potential restriction on PFAS in fire-fighting foams

Cost	Low estimate	Best estimate	High estimate	Notes
One-off costs				
Disposal of stocks (**only Scenario 2**)	€210 million	€320 million	€435 million	Range based on central estimate cost per litre and likely range of tonnage to be disposed of. When considering full range of cost per litre, the range of total disposal

147 Avoided remediation cost would be considered a one-off benefit due to the long timescales of accumulated releases that lead to remediation. They could amount to in the range of hundreds of millions to billions of Euros. Annualised over 15 years, using a 4% discount rate, this would be equal to tens to hundreds of millions of Euros per year (annualisation method is described in more detail below).

148 https://echa.europa.eu/documents/10162/23036412/sea_restrictions_en.pdf/2d7c8e06-b5dd-40fc-b646-3467b5082a9d

149 The discount rate has been chosen as per the example in the ECHA guidance and as recommended by the European Commission's Better Regulation Guidelines. In accordance with ECHA guidance on SEA for restrictions, the annualised costs is calculated as the annualisation factor multiplied by the one-off costs. The annualisation factor is equal to $r(1+r)^n / ((1+r)^n - 1)$, where r is the discount rate and n the cumulative time period.

Cost	Low estimate	Best estimate	High estimate	Notes
				costs could be €60m - €4.8bn (see Section 8.2 l.).
Cleaning of equipment	€100 million (hypothetical 10% of best estimate)	€1.0 billion	€1.5 billion (hypothetical 150% of best estimate)	Best estimate based on the only cleaning process (and associated concentration of <1000ppt remaining PFAS achieved) for which a cost was available. Note that costs could be higher in Scenario 2 than Scenario 1, due to the shorter time available for cleaning, but no specific data was available to quantify this.
Replacement of foam stocks (only Scenario 2)	€320 million	€1.0 billion	€2.0 billion	Range based on central estimate prices per tonne of PFAS-based foam and alternatives, and likely range of tonnage of alternatives to be purchased. When considering full possible range of prices per tonne, the range of total replacement cost could be - €60m - €8.3bn (see Section 8.2 e.).
Total one-off costs	***€100 million (Scenario 1) €630 million (Scenario 2)***	***€1 billion (Scenario 1) €2.3 billion (Scenario 2)***	***€1.5 billion (Scenario 1) €3.9 billion (Scenario 2)***	As per the notes above, the possible range could be even wider (low estimates €530m lower, high estimates €10.7bn higher).
Annualised total one-off costs	***€9.0 million (Scenario 1) €57 million (Scenario 2)***	***€90 million (Scenario 1) €210 million (Scenario 2)***	***€130 million (Scenario 1) €350 million (Scenario 2)***	As per the notes above, the possible range could be even wider (low estimates €48m lower, high estimates €960m higher).
Annual costs				
Additional volumes of alternative foams	€21 million (Scenario 1) € several millions (Scenario 2)	€27 million (Scenario 1) €10 million (Scenario 2) (assumed mid-point between low and high estimate)	€30 million (Scenario 1) €20 million (Scenario 2) (assumed value <€30 million)	Under Scenario 2, all PFAS foam stocks are replaced with new alternative foams at the beginning of the assessment period (already covered under the one-off cost replacement of foam stocks" above). These new foams would not expire within the assessment period, but an unknown share would be used and still need to be replaced again with new foams, thus incurring the costs associated with additional volumes again. Therefore, this cost is lower under Scenario 2 but it cannot be quantified by exactly how much.
Disposal of expired foams	-€ several millions	-€1 million (assumed mid-point between low and high estimate)	-€100,000	

Cost	Low estimate	Best estimate	High estimate	Notes
Clean-up	-€10s of millions	-€10 million (assumed mid-point between low and high estimate)	-€1 million (assumed value close to €0)	High estimate based on the assumption that at least in some cases, savings from reduced clean-up will be incurred, so total savings will be somewhat larger than €0.
Treatment of fire-water run-off per incident (annual unknown)	-€10s of millions	-€ several millions (assumed mid-point between low and high estimate)	€0	
Total annual costs	***-€ 10s of millions (i.e. a benefit)***	***€ several millions (Scenario 1) -€ several millions (i.e. a benefit) (Scenario 2)***	***€29 million (Scenario 1) €19 million (Scenario 2)***	
Total annual costs + annualised one-off costs	***-€ 10s of millions (Scenario 1) ~€0 (Scenario 2)***	***~€100 million (Scenario 1) ~€200 million (Scenario 2)***	***€160 million (Scenario 1) €370 million (Scenario 2)***	As per the notes above, the possible range could be even wider (low estimates €48m lower, high estimates €960m higher).

Results rounded to two significant figures.

Cost effectiveness

Based on the above, as a central estimate, it is calculated that the cost effectiveness could be around €850 (Scenario 1) to €1,700 (Scenario 2) per kg of annual reduction of PFAS emissions. This could range from savings in the tens of Euros per kg to costs around €10,000 per kg.

Table 8.18 Estimate of cost-effectiveness of the reduction of PFAS emissions from fire-fighting foams

	Low estimate	Best estimate	High estimate
Total emission reduction per year (kg)	234,000 kg	117,000 kg	36,000 kg
Total cost per year (€)	-€ 10s of millions (Scenario 1) ~€0 (Scenario 2)	€100 million (Scenario 1) €200 million (Scenario 2)	€160 million (Scenario 1) €370 million (Scenario 2)
Cost-effectiveness	-€ 10s /kg (Scenario 1) €0/kg (Scenario 2)	€850/kg (Scenario 1) ~€1,700/kg (Scenario 2)	€4,600/kg (Scenario 1) €10,000/kg (Scenario 2)

Results rounded to two significant figures and reflect the likely range. However, as noted in the previous table, the range could possibly be even wider, from -€ 10s /kg (both Scenarios) to €31,000/kg (Scenario 1) and €37,000/kg (Scenario 2).

Assumptions and uncertainties

The above conclusions are subject to a range of assumptions and uncertainties. Assumptions have been made based on the results of other tasks and are discussed in more detail within those tasks. However, the assumptions and uncertainties that could most significantly affect the results are discussed briefly below:

- Environmental/health benefits of the reduction of PFAS emissions could not be quantified, primarily due to a lack of knowledge about the hazards of PFAS. The estimated emissions of

PFAS and hazards of the constituents of alternatives are also subject to a range of uncertain assumptions. Hence, costs and benefits could not be directly compared;

- Cost of transition are subject to uncertain assumptions about price difference between foams and the quantity of alternative foams needed to achieve the desired performance. Which and how much alternative foam is needed to achieve the desired performance varies on a case by case basis. It has been judged most likely that there is no significant price difference (per litre) between PFAs-based foams and alternatives, and assumed that 50% additional volume of alternatives is needed. If a more/less expensive alternative foam or larger/smaller quantities would be needed to achieve the desired performance, this would increase/decrease the costs of the restriction. Savings related to the transition are sensitive to assumptions about the amounts of foam that would reach their expiry date without use under the baseline;
- Costs of cleaning and technical changes or replacement of equipment are very case-specific and could largely not be quantified with the available data. This means that the quantified costs of both scenarios are underestimates;
- It should be noted that there was a divergence in the stakeholder input about technical feasibility of alternatives. A few stakeholders have voiced concerns over the potentially reduced fire safety, at least in specific applications. This means there is a risk of additional health, safety and economic (fire damage) impacts; however our analysis has concluded that they are not the most likely outcome and that LAST are the main application for which there is still further testing required;
- It is uncertain to what extent current practices involving the use of PFAS-based fire-fighting foams already manage to eliminate the need for significant new remediation requirements under the baseline. This is because most experiences with PFAS remediation relate to legacy contamination resulting from historical emissions before current measures (e.g. containment and clean-up after use) were widely implemented. However, stakeholder input suggests that such measures are likely not 100% implemented or effective. Furthermore the incremental costs of addressing PFAS contamination in short-term clean-up is difficult to separate from the wider clean-up costs involved after fire incidents. In addition, there is a lack of data about the number of sites that use PFAS-based foams in sufficient quantities to potentially require clean-up or large scale remediation. Therefore remediation savings from the transition to fluorine-free alternatives are very uncertain and only illustrative estimates of the potential order of magnitude of such benefits were provided; and
- There is a wide range (€60-4,800 million, with best estimate €320 million) in the potential costs of disposal of legacy foams in Scenario 2, which largely depends on the disposal method used. This is due to uncertainty about the amounts of foam that would reach their expiry date without use under the baseline and the effectiveness of PFAS-destruction at different incineration temperatures and times. There is also uncertainty about the potential emissions and therefore associated environmental/health risks.

PART 4 – pre-RMOA

9. Task 5. Regulatory management option analysis (pre-RMOA)

9.1 Introduction

The aim of the risk management option analysis (RMOA) is to identify the most appropriate regulatory instrument for possible risk management activities to address the concerns related to PFAS used in fire-fighting foams. As such, it covers a range of different substances that have been identified in Section 3.

The structure of this section is based on ECHA guidance[150] but has been adapted given its focus on a range of substances. This adapted RMOA format was agreed with the European Commission and ECHA. The RMOA is structured as follows:

- First, Section 9.2 briefly summarises the concern associated with the use of PFAS. This does not preclude any results on hazards of PFAS based on the (ongoing) work of the PFAS working group, which were not available for inclusion in this report;
- Section 9.3 puts this into the context of their use in fire-fighting foams in Europe (based on the market analysis in Section 4), and resulting releases to the environment (based on the results from Section 5), in order to assess in which applications and at what scale this use may lead to concerns;
- Section 9.4 provides an overview of existing measures to assess the extent to which the concerns are already addressed;
- Section 9.5 then elaborates on the need for potential further regulation at EU level, based on whether the existing measures are sufficient to address the concern;
- Potential regulatory management options are presented and assessed in Section 9.6. This includes their effectiveness in controlling the risks, considerations relating to alternatives and socio-economic impacts (based on the results of the ECHA study in Sections 7-8 and the assessment of remediation costs in Section 6) and other regulatory considerations (e.g. practicality and monitorability); and
- Finally, Section 9.7 draws conclusions based on the assessment of regulatory management options and preliminary socio-economic considerations.

9.2 Hazard information

Introduction

A PFAS working group exists under ECHA's stewardship to assess the hazards associated with PFAS substances, including persistence, mobility, bioaccumulation and toxicity. To avoid duplication with the work

[150] Such as the internal RMOA templates used by ECHA, or ECHA (2007) Guidance for the preparation of an Annex XV dossier for restrictions, available from: https://echa.europa.eu/documents/10162/23036412/restriction_en.pdf/d48a00bf-cd8d-4575-8acc-c1bbe9f9c3f6

of the PFAS working group an in-depth assessment of the hazards for PFAS substances (as a family of chemicals used for fire-fighting foams) has not been completed under the current study. Therefore, based on the wealth of research that has already been developed, high level comments on the hazards associated with PFAS substances are provided here, in order to support the pre-RMOA and provide context on the need for action at the EU level. Further discussion on the hazards of the non-fluorinated alternatives is provided in Section 5.

Overview

PFAS is a broad term used to cover approximately 4,700 specific chemical species[151] which have a wide range of uses. These uses are principally based around the carbon-fluorine bond which is particularly strong and offers physical properties that include high water and oil repellence[152]. The same properties mean that many PFAS substances are also highly mobile (within the natural environment) and highly persistent (see Appendix 3). This can create issues where PFAS substances emitted to the environment reach and contaminate important resources such as groundwater. There is evidence to suggest that exposure to PFAS can lead to adverse health effects in humans (by eating or drinking food or water contaminated by PFAS). In particular the US EPA[153] highlight studies that indicate the longer chain (C8 PFAS) species PFOS and PFOA can cause reproductive and developmental, liver and kidney, and immunological effects on laboratory animals. Furthermore, both chemicals have caused tumours in animal studies. Their use is already restricted in the EU and elsewhere. Some short-chain PFAS (PFHxS, PFBS, HFPO-DA) have also been listed as SVHCs, based on there being an equivalent level of concern to the named groups of chemicals under the authorisation provisions under REACH (carcinogens, mutagens and reprotoxicants (CMRs) and persistent, bioaccumulative and toxic/very persistent and very bioaccumulative (PBTs/vPvBs) chemicals).

The Nordic Council of Ministers[154] commented that the annual health-impacts within an EEA exposure study (from all uses of PFAS, not only fire-fighting foams) was estimated at €52-84 billion. This gives an indication of the scale of the issue and magnitude of the potential impacts from the environmental build-up of PFAS. The same study describes remediation costs associated with contamination from PFAS at European sites ranging from several hundred thousand up to €40 million with one high-cost example for the Dusseldorf Airport, Germany estimating a total remediation cost of up to €100 million.

Based on the physical properties of PFAS (particularly mobility and persistence) along with identified health effects for some PFAS, PFAS represent a challenging environmental and human health hazard issue.

9.3 Information on tonnage, uses and exposure

This section provides an overview of the applications in which PFAS-based fire-fighting foams and fluorine-free alternatives are used, along with associated tonnages (based on the results of Section 4), as well as the resulting releases to the environment (based on the results of Section 5). This is intended to put the hazards discussed in the previous section into context and allow for an assessment of the concern resulting from the use of PFAS-based fire-fighting foams and fluorine-free alternatives.

Uses

The main function of PFAS contained in fire-fighting foam is to act as a surfactant, that is to form a film over the surface of a burning liquid in order to prevent flammable gases from being released from it as well as

[151] OECD, 2018, PFAS database, toward a new comprehensive global database of per and polyfluoroalkyl substances.
[152] Buck et al, 2011, 'Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification and origins', Integrated environmental assessment and management vol 7 issue 4.
[153] US EPA, 2019, 'Basic information on PFAS', https://www.epa.gov/pfas/basic-information-pfas
[154] Nordic Council of Ministers, 2019, 'The Cost of Inaction – A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS', *http://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf*

reigniting. They are therefore used in fires involving flammable liquid (Class B fires) within a range of sectors. Tonnages of foam used by sector are discussed in the next sub-section below. According to the consultation, PFAS-based fire-fighting foams are used for training and testing of equipment, and in many levels of fire hazards, from small fire extinguishers to large tank fires, and can be applied both with mobile and semi-stationary equipment.

Fluorine-free alternatives are in principle used in the same applications and are increasingly replacing PFAS-based foams, although with varying market penetration depending on the sector or specific application. In some cases, fluorine-free foams have replaced PFAS-based foams in training and testing (as recommended by some industry best practice guidance documents[155]) but not in real fire incidents. The substance identification identified the following groups of substances that PFAS-free fire-fighting foams are based on: hydrocarbons, detergents, siloxanes, and protein foams. According to the consultation, foams based on hydrocarbons and detergents appear to be the most frequently used fluorine-free foams.

Tonnages

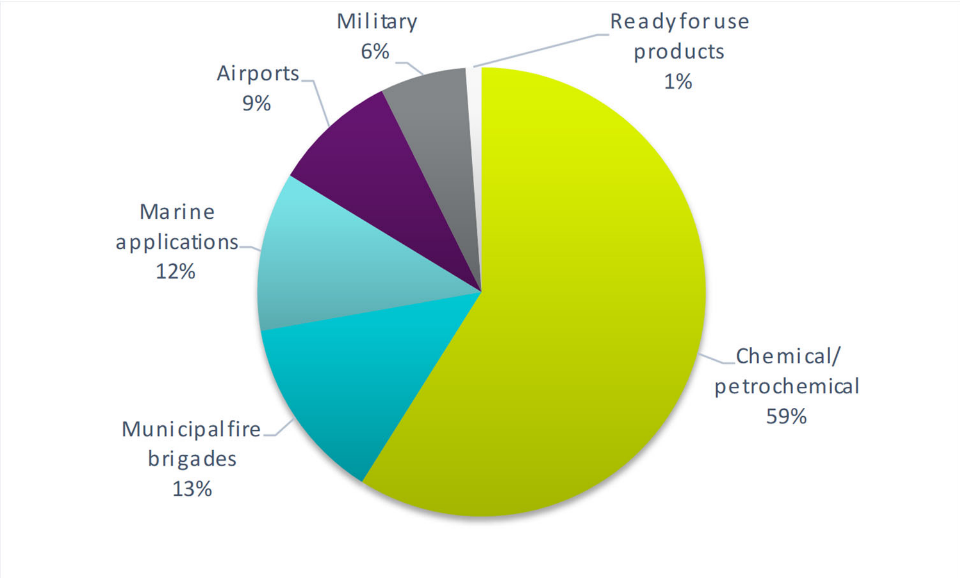
PFAS-based fire-fighting foams

Based on an extrapolation of data provided by Eurofeu it is estimated that **some 20,000 tonnes of PFAS-based fire-fighting foams are sold in the EU per year**. Of these, about 12,000 tonnes are estimated to be employed in fixed systems and 8,000 in mobile systems[156]. The split by sector is detailed in Figure 9.1 below. This shows that **chemical/petrochemical is by far the largest user sector (59%)**, but municipal fire brigades, marine applications, airports and military applications also account for significant volumes. Ready-for-use products only account for a very small share of PFAS-based foams according to this data. The majority of this category are fire extinguishers, although not all foam fire extinguishers use ready-for-use foams (according to personal communications with Eurofeu). The annual tonnage of PFAS-based fire-fighting foam used in all extinguishers in the EU has been estimated at 360-675 tonnes (not counting the water that foam concentrates are mixed with in the extinguishers before/during use).

[155] See for instance https://www.fffc.org/

[156] All these figures have been extrapolated from the original values provided by Eurofeu, which covered approximately 70% of the market. The number of companies that provided a response on whether the foams are used in fixed or mobile systems is lower than those that provided a response for the sectoral overview, therefore in the original data the total tonnage of the former is lower than the latter. To fill this gap, the tonnages for both fixed and mobile systems have been inflated so that their total matches the total in the sectoral split.

Figure 9.1 Split of PFAS-based fire-fighting foams by sector



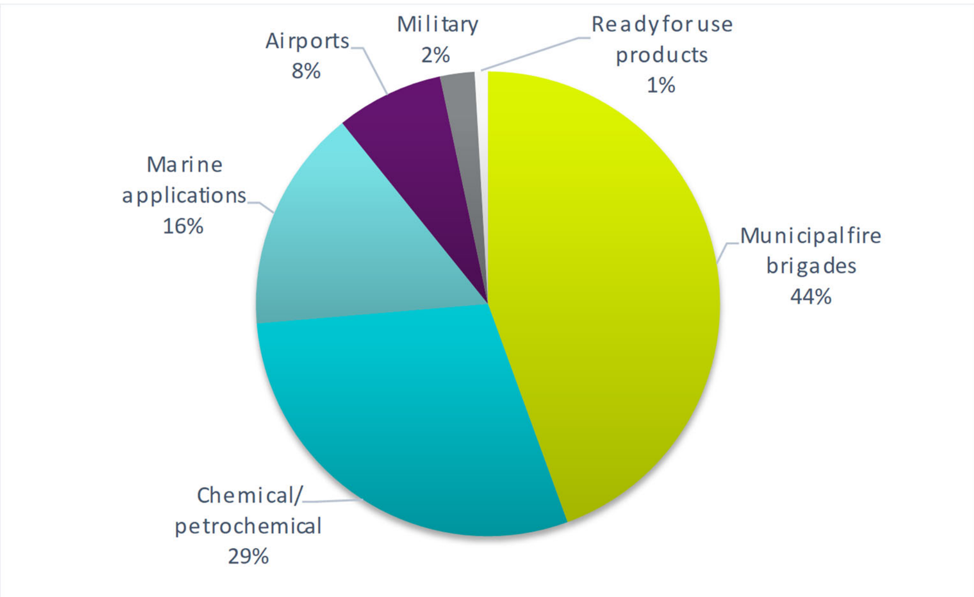
Source: Data provided to the authors by Eurofeu.

The use of these PFAS-based foams accounts for an **annual consumption of around 480-560 tonnes of fluorosurfactants per year in the EU**, based on data provided by Eurofeu.

Fluorine-free fire-fighting foams

As for PFAS-based foams, based on an extrapolation of data provided by Eurofeu it is estimated that **some 9,000 tonnes of fluorine-free foams are sold in the EU per year**. Of these, about 3,000 tonnes are used in fixed systems and 6,000 tonnes in mobile systems[156]. The split by sector is detailed in the figure below. Notably, it varies considerably from that of PFAS-based foams, with a **much larger share used by municipal fire brigades (44%) but a much smaller share in the chemical/petrochemical sectors (29%).**

Figure 9.2 Yearly use of fluorine-free firefighting foams by sector.



Source: Data provided to the authors by Eurofeu.

Exposure

Using a source-flow model and various assumptions that are outlined in Section 5, emission estimates have been developed to provide an illustrative assessment to help better understand the material flow and key emission compartments of fire-fighting foams.

The source-flow model has been used to produce emission estimates for 10 unique non-fluorinated substances (hydrocarbons and detergents); as well as two PFAS-based substances. Tables 7.5 and 7.6 provide summary overviews (as percentage ratios) of the key emission compartments and life-cycle stages for emissions. The initial overview of Table 7.5 highlights that **fresh surface water and soil are the key receiving environmental compartments**. Furthermore, Table 7.6 highlights that, **for non-fluorinated substances, live incidents are the major** point of release, while **for PFAS the waste phase is the key life-cycle stage for emissions**, primarily from losses associated with releases at WWTPs.

Table 9.1 Overview of ratios for emissions by different environmental compartment for all life-cycle stages combined.

Substance group	Air	Fresh surface water*	Marine waters	Soil
Non-fluorinated alternatives (range)	9 – 18%	33 -37%	10 – 15%	30 – 45%
Non-fluorinated alternatives (mean average)	14%	35%	13%	38%
1-Propanaminium,N-(carboxymethyl)-N,N-dimethyl-3-[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulfonyl]amino]-,inner salt	9%	51%	8%	32%
1-Propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-N-[[(gamma-omega-perfluoro-C6-C16-alkyl)thio]acetyl] derives., inner salts	9%	30%	8%	53%

*includes releases from WWTPs after treatment.

Table 9.2 Overview or ratios for emissions by different life-cycle stages

Substance Group	Formulation	Storage and Training	Live	Waste
Non-fluorinated alternatives (range)	9 – 18%	12 – 18%	40 – 62%	1% - 35%
Non-fluorinated alternatives (mean average)	14%	15%	52%	19%
PFAS based substances (mean average)	9%	9%	30%	52%

Regarding the emissions by environmental compartment, it should be noted that while the non-fluorinated fire-fighting foams make up approximately one third of the market, the volumes of alternative surfactants can be greater than their PFAS counterparts **due to greater concentrations within the product itself**, **potentially leading to higher emissions of the non-fluorinated alternatives**. However, it is important to recognise that emission alone is not an indicator of impact, and the degradation rates, potential for bioaccumulation, and harmful effects also need to be considered (as discussed in the previous section).

Regarding the emissions by life cycle stage, it should be noted that the major use of fire-fighting foams is for **training purposes**. During training exercises, aside from marine applications, it is assumed that the efficacy of bunding and/or other control measures is relatively good. This means much of the fire-fighting concentrate within runoff is contained and sent for final destruction primarily within waste water treatment plants (WWTPs) on-site or off-site. **For the non-fluorinated alternatives, the effectiveness of WWTPs is relatively good**, minimising the emission which is split between surface water and soil. Because WWTPs are more effective in irreversibly destroying the named non-fluorinated substances, their use in training where run-off can be contained and treated leads to relatively low releases to the environment. This increases the relative importance of live incidents – where there is a direct release without treatment. **For the PFAS-based substances, WWTPs is expected to be ineffective at treating PFAS**, meaning direct release to surface water / soil depending on the partition coefficient. Waste is thus the most important life-cycle stage for the PFAS substances.

9.4 Overview of current measures

International Measures

Stockholm Convention

The Stockholm Convention on Persistent Organic Pollutants (POPs) includes restrictions on the production and use of a number of specific PFAS, at international level, including some provision for exemptions for the production and use of these compounds for use in firefighting foams.

PFOS, its salts and PFOSF are listed under Annex B of the Stockholm Convention, which restricts production and use to specified acceptable purposes and specific exemptions. Upon its initial listing in 2009, an acceptable purpose was put in place for PFOS used in firefighting foams. At the POPRC meeting in 2018, the committee recommended, based on the findings of an assessment of alternatives to PFOS[157] , that the acceptable purposes for the production and use of PFOS, its salts and PFOSF for fire-fighting foam be amended to a specific exemption for the use of fire-fighting foam for liquid fuel vapour suppression and liquid fuel fires (Class B fires) already in installed systems, including both mobile and fixed systems, and with the same conditions put in place for PFOA (see below). This exemption was agreed accordingly at the Ninth Meeting of the Conference of the Parties (COP) to the Stockholm Convention in 2019.

At the 14th meeting of the POPRC in September 2018 the POPRC recommended listing PFOA, its salts and PFOA-related compounds in Annex A to the Convention with specific exemptions. One exemption specified was for use of firefighting foams containing PFOA already installed in systems including both mobile and fixed systems with specific conditions. Parties to the Convention can register for this exemption if they: i) ensure that FFFs that contain or may contain PFOA shall not be exported or imported except for the purpose of environmentally sound disposal; ii) do not use FFFs that contain or may contain PFOA for training or testing (unless all releases are contained) purposes; iii) by the end of 2022 if possible, but no later than 2025, restrict uses of FFFs that contain or may contain PFOA, to sites where all releases can be contained; iv) ensure all fire water, waste water, run-off, foam and other wastes are managed. This was also agreed accordingly at the 9th COP in 2019.

At its fifteenth meeting, the POPRC adopted the risk management evaluation on perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds and recommended to the Conference of the Parties that it consider listing the chemicals in Annex A to the Convention without specific exemptions. The listing will not be officially adopted until the next COP meeting in May 2021, and would be officially added to the Annexes of the Convention in 2022.

[157] UNEP/POPS/POPRC.14/INF/8 : http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC14/Overview/tabid/7398/Default.aspx

EU Regulation

The European Union has implemented the POPs Regulation (EC 2019/1021)[158] which acts to implement the provisions of the Stockholm Convention across the EU Member States.

PFOS was originally included in the restricted substances list of REACH. However, since its addition to the Stockholm Convention in 2009, it has been regulated under the POPs Regulation. PFOS, its salts and PFOSF are listed under Annex I of the POPs Regulation, specifying the following exemptions for unintentional trace contaminants (UTC)[159]:

- Substances or preparations (<10 mg/kg); and
- Semi-finished products or articles, or parts (<0.1 % by weight).

An exemption is also foreseen for the use as mist suppressant for non-decorative hard chromium plating.

PFOA has been identified under REACH as a SVHC since 2013 and it is restricted under entry 68 of Annex XVII. However, the restriction includes an exemption for PFOA used in concentrated fire-fighting foam mixtures placed on the market before 4 July 2020 and those used in the production of other fire-fighting foam mixtures. There is also an exemption for use in fire-fighting foam mixtures produced before 4 July 2020 and used for training purposes, provided that emissions to the environment are minimised and effluents are collected and safely disposed of. The POPs Regulation is expected to be amended in summer 2020 to include PFOA in Annex I following the listing under the Stockholm Convention (see above). The derogations for fire-fighting foams proposed under the POPs Regulation are more limited compared to the REACH restriction, as the listing under the Stockholm Convention allows no derogation for use in training; it only allows use of foams in installed systems, only until 2022 (or 2025 at the latest), and only with containment requirements.

PFHxS, has, since June 2017, also been listed as an SVHC under REACH and there is an ongoing restriction proposal[160] (at the time of writing at the stage of public consultation on the SEAC draft opinion). It is expected that PFHxS will ultimately also be regulated at EU-level under the POPs Regulation, when its listing to the Stockholm Convention is finalised (see above).

In December 2019, a proposal[161] for a restriction under REACH on PFHxA was published. The proposal includes certain transition periods and derogations for uses in fire-fighting foams. It is proposed that concentrated fire-fighting foam mixtures placed on the market until 18 months after the entry into force of the restriction could still be used in the production of other firefighting foam mixtures until 5 years after the entry into force, except for use of fire-fighting foam for training and (if not 100% contained) testing. There is also an exception for concentrated fire-fighting foam mixtures for certain defence applications until a successful transition to alternatives can be achieved, and for concentrated fire-fighting foam mixtures for cases of class B fires in storage tanks with a surface area above 500 m^2 until 12 years after the entry into force.

Other international controls

In 2016, The Swedish Chemicals Agency (KEMI) published its strategy for reducing the use of PFASs[162] beyond solely the implementation of EU legislation.

This included specific measures to tackle PFAS in firefighting foams, including a proposal for national regulations covering, for example:

- Legal requirement for the collection and destruction of fluorine-based fire-fighting foam;

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158 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R1021&from=EN

159 There is an exemption for the use in hard chromium plating, although that is not relevant for fire-fighting foams.

160 https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e1827f87da

161 https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18323a25d

162 https://www.kemi.se/global/rapporter/2016/report-11-16-strategy-for-reducing-the-use-of-higly-fluorinated-substances-pfas.pdf

- Imposing reporting requirements; and
- Review of exemptions - with the aim of reducing the number of exemptions as much as possible.

In some non-EU countries, there are also regulations in place, specifically targeting PFAS in firefighting foams. For example, in Norway[163], there are regulations in place that focus on the following:

- The monitoring and screening of PFAS in the environment in general;
- The monitoring and clean-up of PFAS polluted soil caused by airport fire drills;
- A requirement for airports to monitor levels of PFAS at their fire drill sites and propose measures to reduce pollution; and
- A requirement for airports to screen and report levels of PFAS in their soil, and must propose measures to reduce pollution.

In the USA, at federal level, the US EPA has developed and launched a PFAS Action Plan[164] to evaluate whether and how to regulate PFAS compounds under various federal environmental programmes (including TSCA). The primary focus of this plan is to reduce environmental and public health concerns when PFAS are released into the environment (e.g., through setting safe drinking water limits and remediation criteria). While the plan specifically references the use of firefighting foams as a key source of PFAS contamination and exposure, it does not set limits or actions specifically at national level for use of PFAS in foams. In December 2019, the Fiscal Year 2020 National Defense Authorization Act (NDAA) was released, which phases out the US Department of Defense's use of PFAS-containing firefighting foam by October 2024 (with an exception for shipboard use) and immediately prohibits the uncontrolled release of fluorinated aqueous film-forming foam (AFFF) and the use of AFFF in training exercises at military installations[165]. It should be noted that individual States also implement their own measures, and there is a wide variety of approaches, measures, and timescales adopted. As an example of some of the States with the strictest approaches:

- Washington bans the sale and the use for training purposes of PFAS-based fire-fighting foams from 1 July 2020 (except for oil refineries, chemical plants and uses required by federal law such as aircraft rescue)[166]; and
- In California, a bill was proposed to the Senate (but not yet passed at the time of writing) to ban, from the beginning of 2022, the placing on the market of fire-fighting foams with intentionally added PFAS, except for uses required by federal law. It also requires manufacturers to recall products affected by the ban by that date, practically banning the use as well[167].

In Australia, the biggest source of concentrated emissions of PFAS is from historical use of PFAS-containing fire-fighting foams, particularly at fire-fighting training grounds. The Industrial Chemicals (Notification and Assessment) Act (ICNA Act), requires industry to provide toxicity data for new substances (including PFASs) or products containing new PFASs being introduced into Australia. Based on the level of toxicity and environmental persistence, the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) recommends restrictions on how these substances can and cannot be used[168].

[163] https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/norway.htm
[164] https://www.epa.gov/sites/production/files/2019-02/documents/pfas_action_plan_021319_508compliant_1.pdf
[165] https://armedservices.house.gov/_cache/files/f/5/f50b2a93-79aa-42a0-a1aa-d1c490011bae/3552B8ED0CB74FB28CC88F434EFB306A.fy20-ndaa-conference-summary-final.pdf
[166] http://lawfilesext.leg.wa.gov/biennium/2017-18/Pdf/Bills/Senate%20Passed%20Legislature/6413-S.PL.pdf?q=20200413062702
[167] https://leginfo.legislature.ca.gov/faces/billCompareClient.xhtml?bill_id=201920200SB1044&showamends=false
[168] https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/australia.htm

Industry Measures

Substitution and phase-out

As noted in several documents under the Stockholm Convention, for over a decade, a number of alternatives to the use of C8-based fluorosurfactants (containing PFAS) in fire-fighting foams have been developed and are now widely available. These include shorter-chain (C6) fluoro-surfactants, as well as fluorine-free fire-fighting foams; and other developing fire-fighting foam technologies that avoid the use of fluorine.

The use of C8-based AFFF has been largely phased out in favour of these alternatives. For example, it is reported that the volume of AFFF-containing PFOS used in the USA declined from around 21 million litres in 2004 to less than 9 million litres in 2011[169].

The POPRC officially recognises that a transition to the use of short-chain per- and polyfluoroalkyl substances (PFAS) for dispersive applications such as fire-fighting foam is not a suitable option from an environmental and human health point of view and that some time may be needed for a transition to alternatives without PFAS (POPRC-14/3).

In the USA, in 2006, the US EPA launched the PFOA Stewardship Program following concerns raised about the impact of PFOA and long-chain PFASs on human health and the environment, including concerns about their persistence and presence in the environment[170]. The programme involved eight major companies[171] committing to reducing PFOA from facility emissions and product content by 95 percent no later than 2010, and to work toward eliminating PFOA from emissions and product content no later than 2015. All participating companies state in the most recent progress reports, that they met the PFOA Stewardship Program goals[172].

In Australia, it has been reported that the Department of Defence commenced phasing out its use of PFOS and PFOA-containing fire-fighting foams and switched to 'Ansulite', which only contains trace elements of PFOS/PFOA and is only used in emergency situations or in controlled environments to test equipment. Furthermore, PFAS use is also limited by Air Services Australia, a government-owned corporation that provides air traffic control management, which has transitioned away from fluorinated firefighting foam to non-fluorinated firefighting foam including the destruction of remaining stockpiles[173].

Containment and control

In Germany[174], it is reported that the regulatory authorities and fire-fighting associations have compiled a leaflet on PFAS in fire-fighting, which has reportedly resulted in an increased awareness of the risks associated with certain PFASs by industry, NGOs and the public.

In Norway[175] it is reported that fluorine-containing fire-fighting foam has been substituted with fluorine-free alternatives in most civil airports and fluorine-containing foam is no longer in use at fire-fighting training sites with the Norwegian military forces. Furthermore, it is reported that PFAS are being gradually substituted with fluorine free-alternatives in the offshore sector, and the volumes of fluorine-containing foam used in this sector are decreasing.

One respondent to the consultation questionnaire conducted for this project reported that the Swedish Petroleum and Biofuels Institute has previously (2011) provided guidance on how to plan and implement the

[169] FFFC (2011) Estimated Inventory Of PFOS-based Aqueous Film Forming Foam (AFFF). 2011 update to the 2004 report entitled "Estimated Quantities of Aqueous Film Forming Foam (AFFF) In the United States". Prepared for the Fire Fighting Foam Coalition, Inc.
[170] https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/fact-sheet-20102015-pfoa-stewardship-program
[171] Arkema, Asahi, BASF, Clariant, Daikin, 3M/Dyneon, DuPont, Solvay Solexis
[172] https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/20102015-pfoa-stewardship-program-2014-annual-progress
[173] https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/australia.htm
[174] https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/germany.htm
[175] https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/norway.htm

prevention of spillage and secondary containment embankments, methods for emergency response, and for the assessment and preventing product tanks to lift off inside water filled bunds/embankments. It was estimated that ~80 % of the member companies were in compliance with this guidance.

The trade association, the Fire Fighting Foam Coalition (FFFC) has published a best practice guidance document for the safe use of firefighting foams for Class B fires[176], with the aim to "foster use of foam in an environmentally responsible manner so as to minimize risk from its use".

The guidance covers the following aspects of Class B firefighting foam use:

- **Foam Selection** – specifying situations where the use of Class B foams is, and is not, recommended, e.g. limiting the use of Class B foams to situations that present 'a significant flammable liquid hazard';
- **Eliminating Foam Discharge** – noting that this is not always possible in emergency situations, but emphasising the possibility to achieve this in training and the testing of foam systems and equipment;
- **Training** – providing guidance on the formulation of training foams, the design, construction and operation of training facilities;
- **Foam System Testing** – including guidance on acceptance tests, conducted pursuant to installation of the system; and maintenance tests (i.e. of firefighting vehicles);
- **Containing Foam Discharge** – guidance to prevent discharge to the environment, both for manual and fixed systems**; and**
- **Firewater and foam concentrate disposal –** with an emphasis on incineration but also covering coagulation, flocculation, electro-flocculation, reverse osmosis, and adsorption on granular activated carbon (GAC).

Similarly, the Fire Protection Association Australia has published a guidance document on the selection and use of firefighting foams[177]. This covers, for example,

- **Factors impacting on selection and use** – including firefighting performance, environmental impact, system and equipment compatibility;
- **Environmental and firefighting performance indicators;**
- **Fluorinated and fluorine-free firefighting foams; and**
- **Environmental best practice -** including training and system testing and commissioning, fire water effluent, remediation of contaminated soil and water, cleaning/change out of existing foams.

The consultation did not yield information on the extent to which these best practice measures outlined by the likes of the FFFC and FPAA are being implemented, or their effectiveness.

9.5 Need for (further) regulatory management

Section 9.2 has illustrated that (without precluding any ongoing work or conclusions by the PFAS working group) there are concerns associated with PFAS. Some PFAS have been shown to cause reproductive and developmental, liver and kidney, and immunological effects as well as tumours in animal studies. Many PFAS

[176] Covering aqueous film-forming foam (AFFF), alcohol resistant aqueous filmforming foam (AR-AFFF), film-forming fluoroprotein foam (FFFP), alcohol resistant film-forming fluoroprotein foam (AR-FFFP), and fluoroprotein foam (FP, FPAR).
[177] FPA Australia (2017)

are highly mobile, highly persistent, and have the potential to accumulate within the environment and living organisms. The assessed non-fluorinated alternatives' persistence is considerably lower than PFAS.

Section 9.3 has shown that, while in some user sectors PFAS-based foams have been increasingly replaced by fluorine-free alternatives and industry best practice guidance recommends not using PFAS-based foams in training and testing, some 20,000 tonnes of PFAS-based fire-fighting foams are still used annually in the EU in applications involving flammable liquid fires (Class B fires), including testing and training. This use leads to releases to the environment, with fresh surface water and soil being the key receiving environmental compartments. For non-fluorinated substances, live incidents are the major point of release, while for PFAS the waste phase is the key life-cycle stage for emissions, primarily from losses associated with releases at WWTPs. Some PFAS were shown to be ubiquitous contaminants, for instance in arctic wildlife[178].

Section 9.4 illustrated that the use of certain PFAS substances has been regulated in the past. This has led to the replacement of the regulated (e.g. long-chain) PFAS with fluorine-free alternatives in some cases, but also other PFAS substances (e.g. short-chain PFAS), as illustrated by the fact that the majority of fire-fighting foams used are still PFAS-based. Concerns have continued that shorter chain PFAS substances are also mobile (if not more mobile) than ≥C8 substances and are highly persistent, albeit with potentially lower bioaccumulation[179]. Some (PFHxS, PFBS, HFPO-DA) have also been listed as SVHCs, based on there being an equivalent level of concern to the named groups of chemicals under the authorisation provisions under REACH (carcinogens, mutagens and reprotoxicants (CMRs) and persistent, bioaccumulative and toxic/very persistent and very bioaccumulative (PBTs/vPvBs) chemicals).

National regulations exist that require the containment of fire-water run-off, but the consultation suggested that containment is rarely 100% effective and there are concerns about the efficacy of removal of PFAS from collected fire-water in WWTP. Industry best practice measures aim to minimise the use and release of PFAS-based foams (e.g. ceasing its use in training and testing, as has happened in many locations already) but the consultation suggested that these are not being fully implemented (e.g. the use of PFAS-based foams in training has been reported). Stakeholder input did not allow to conclude on their relative effectiveness.

In conclusion, it has been demonstrated that the use of PFAS in fire-fighting foams is associated with a significant environmental concern that does not seem to be adequately addressed by the current measures in place. Even if additional measures were introduced at Member State level (and the consultation has not raised anything suggesting that they will be), there is potential for discrepancies in the definitions and scope of any national restrictions (e.g. definition of substances covered, uses covered, concentration thresholds, transition periods). This has implications not only for the degree to which the environment is protected, but also in terms of ensuring the functioning of the internal market. Different restrictions in different Member States could make it very challenging to market fire-fighting foam products saleable in all Member States. Moreover, due to their high mobility and persistence as well as their proven ubiquity (at least of some PFAS), it appears very likely that PFAS emissions lead to cross-border pollution. Therefore potential further regulatory management on EU-level is likely required. Potential options are discussed in the following section.

9.6 Identification and assessment of regulatory management options

This section identifies the different options and assesses their suitability. The assessment follows relevant ECHA guidance[180] on Annex XV for restrictions based on the following criteria (ECHA 2007):

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178 See for instance Muir, D. et al. (2019): Levels and trends of poly-and perfluoroalkyl substances in the Arctic environment–An update. *Emerging Contaminants*, *5*, 240-271.

179 Cousins et al, 2018, 'short-chain perfluoroalkyl acids: environmental concerns and regulatory strategy under REACH', Environmental science Europe vol 30.

Appendix 3

180 ECHA (2007) Guidance for the preparation of an Annex XV dossier for restrictions, available from: https://echa.europa.eu/documents/10162/23036412/restriction_en.pdf/d48a00bf-cd8d-4575-8acc-c1bbe9f9c3f6

- Effectiveness: Is the option targeted at the effects or exposures that cause the identified risks, capable of reducing these risks to an acceptable level within a reasonable period of time, and proportional to the risk?
- Practicality: Is the option implementable, enforceable and manageable?
- Monitorability: Is it possible to monitor the implementation of the option? and
- Considerations relating to alternatives and socio-economic impacts.

It was agreed in discussions with the steering group to assess two main regulatory management options (RMOs):

1) Restriction (ban) on the **placing on the market** of PFAS-based fire-fighting foams (hereafter referred to as ***Scenario 1***). The use of legacy foams, i.e. foams already in stock at producers' or users' sites, is still permitted; and
2) Restriction (ban) on the **placing on the market and the use** of PFAS-based fire-fighting foams (hereafter referred to as ***Scenario 2***). The legacy foams, i.e. foams already in stock at producers' or users' sites, should be disposed of safely.

In the following, first these two main options are discussed and compared. Then, the specific conditions of the restrictions are discussed across both options, including potential sector- or application-specific conditions, transition periods, allowed residual PFAS concentrations in foams and the application of specific Risk Management Measures (RMMs).

Comparison of the RMOs

Effectiveness

Both scenarios will eventually lead to an elimination of the use and therefore the emissions of PFAS-containing fire-fighting foams. Therefore, they can both be considered effective in addressing the identified concern. The reduction of emissions would be achieved more quickly in Scenario 2 and therefore Scenario 2 would also achieve a higher reduction of cumulative PFAS contamination.

The shelf life of PFAS-based foams is reported to be typically between 10 and 20 years (to a maximum of 30 years)[181], so in Scenario 1 some (decreasing) emissions of PFAS-based foam could continue for a long period after the entry into force of the restriction. Based on the annual sales and average lifetime of fire-fighting foams, it is estimated that the stocks of PFAS-based fire-fighting foams in existing systems may be between 210,000 and 435,000 tonnes (see Section 8.1). However, it is uncertain what share of foams in existing systems would be used (and hence to some extent emitted) and what share would be replaced at the end of their shelf life or replaced voluntarily (and hence disposed of safely).

It should be noted that in Scenario 2, there are potential risks of emissions from the incineration of legacy foams, but further research is needed to identify and quantify the emissions produced from the incineration of PFAS.

Practicality and monitorability

In principle, both options appear practical and monitorable, as there are already other regulations in place controlling the placing on the market and use of fire-fighting foams. However, as Scenario 2 covers the use in addition to the placing on the market (which is also covered under Scenario 1), it is subject to more complex

[181] Proposal for a restriction: Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related substances https://echa.europa.eu/documents/10162/a22da803-0749-81d8-bc6d-ef551fc24e19

requirements in terms of implementation, enforcement, management and monitoring, compared to Scenario 1.

One stakeholder pointed out the following practicality issue for Scenario 1. When large amounts of foam are used for an incident, foam tanks need to be quickly refilled to allow continued operation, sometimes even during the same incident. However, it is not recommended to mix different foams in the same system (because this could affect performance and the new foam would be contaminated with PFAS from the old foam), so refilling during an incident would not be feasible if PFAS-foam was used in existing systems. This could potentially lead to end-users building up stocks of PFAS-based foams before the restrictions comes into place, or it could potentially lead to users not replacing foams in existing systems to save costs causing problems during a large incident when a refill during the incident would be needed.

Socio-economic impacts

The socio-economic implications of both scenarios are discussed in more detail in Section 8 (Section 8.3 in particular summarises the overall impacts and the differences between the two scenarios). However, a briefer summary of key points is provided here to support the conclusions of this section.

Both scenarios require purchasing of alternative foams which is estimated to incur additional costs (compared to the baseline) of around €27m per year in the EU. In Scenario 2, these costs would be incurred immediately when the restriction comes into force (or before), whereas in Scenario 1 the costs increase gradually and only reach €27m per year once all stocks are depleted. This would be partly off-set by savings, e.g. from lower disposal cost of fluorine-free foams when they reach their expiry date. However, Scenario 2 would also require existing stocks of PFAS-based foams (estimated 210,000-435,000 tonnes) to be written off (considering depreciation since their purchase), and new stocks would have to be purchased, subject to replacement costs (minus the value of existing stocks already depreciated) estimated at around €1.0 billion (range -€60 million[182] to €8.3 billion).

In Scenario 2, additional costs would also be incurred for the disposal of the existing stocks of PFAS-based foams. Total EU costs (one-off) are estimated at up to €320 million (range up to €60m-€4.8bn) depending on the method used and the share of foams that would have reached expiry date without use (whose disposal is merely brought forward by the restriction, but costs are not additional to the baseline). There is a trade-off between the disposal costs and the mitigation of potential environmental risks from disposal (as discussed above). Additional transport, storage and labour costs have not been quantified.

There are other potential economic costs for transitioning that are difficult to quantify, of which cleaning/replacement of equipment before switching the foam are likely the most important. These costs could be significant (e.g. cleaning could potentially be in the order of €1 billion, depending on the residual concentration limit and number of installations affected). They are not likely to vary significantly across the two options but could be more spread over time under Scenario 1.

Alternatives are generally considered to be technically feasible in most applications. Further testing is required to confirm the technical feasibility of alternatives for specific applications, particularly large atmospheric storage tanks. The speed of fire suppression may be slower and application of foams may be less flexible and less easy to use (e.g. different foams may be needed for different flammable liquids), in some cases. In Scenario 1 some of these risks would be mitigated for as long as stocks of PFAS-based foams in existing systems are being used for the cases in question.

There are potentially significant benefits in terms of reduced clean-up / remediation costs. As a very high level estimate for illustration, the potential order of magnitude of avoided remediation could be hundreds of millions or Euros (assuming tens of sites requiring remediation at tens of millions of Euro per site) to billions of Euros (assuming hundreds of sites requiring remediation at tens of millions of Euro per site). More

[182] I.e. a potential saving of €60 million, if fluorine-free alternatives are less expensive than the PFAS-based foams they replace (possible in some cases but unlikely on average) and no additional volumes are required.

information on the total number of sites, real-world use of PFAS per site as well as implementation and effectiveness of best practices in terms of containment and immediate clean-up would be required to assess to which extent remediation is likely to be required in the future as a result of current use of PFAS-based fire-fighting foams (and could therefore be avoided because of the restriction). Any such benefits would be higher in Scenario 2, given the quicker elimination of PFAS emissions and higher reductions of accumulated PFAS contamination.

Treatment of fire-water run-off and short-term clean-up after the use of fire-fighting foams is largely driven by other components of the fire-water run-off, rather than the foam used. At least in some cases, run-off treatment costs could be around €0.7 per litre (range ca €0-€11) or up to tens of millions of Euro per incident cheaper when fluorine-free foams are used, but data on the total amount of fire-water run-off treated was lacking to quantify an EU total. In cases where fire-water run-off is not contained and further clean-up is possible, clean-up costs may also be lower for fluorine-free foams due to their lower persistence. No specific data was available to quantify this saving, but for illustration the potential order of magnitude of savings be could be several million Euros (assuming several tens of incidents per year using PFAS-based foams where clean-up is required and which could be avoided if fluorine-free foams were used). Again, any such benefits would be higher in Scenario 2, given the quicker elimination of PFAS emissions and higher reductions of accumulated PFAS contamination.

It is considered unlikely that either scenario will cause any significant macroeconomic impacts (e.g. employment, trade).

Conclusion

The key consideration in judging and comparing the appropriateness of the two RMOs is the balance between their effectiveness (i.e. the reduction of PFAS emissions) and their socio-economic impacts (primarily the costs of transitioning to fluorine-free foams and potentially fire-safety risks from using alternatives, off-set partly by benefits of reduced clean-up / remediation). As the environmental/health benefits of reduced PFAS emissions (and indeed some of the socio-economic impacts) could not be quantified, it is not possible to use cost-benefit analysis to directly assess if the proposed intervention is proportionate. ECHA's approach to the "Evaluation of restriction reports and applications for authorisation for PBT and vPvB substances in SEAC"[183] uses the cost per unit (e.g. kilogram) of emission reduced. Based on the quantifiable socio-economic impacts, as a central estimate, it was calculated that the cost effectiveness could be around €850 (Scenario 1) to €1,700 (Scenario 2) per kg of annual reduction of PFAS emissions. However, this could range from savings in the €10s per kg to costs around €10,000 per kg.[184]

Therefore, the approach adopted in the following is to identify the uses/applications and conditions (transition periods, concentration thresholds, other risk management measures) that would achieve relatively high levels of effectiveness (i.e. reductions of PFAS emissions) with relatively small adverse socio-economic impacts.

Specific conditions for different uses

The various user sectors and applications of fire-fighting foams vary significantly in terms of the potential for a restriction to reduce PFAS emissions to the environment ('PFAS risk reduction potential'), the feasibility of transitioning to fluorine-free alternatives ('substitution potential') and the resulting potential socio-economic

[183] https://echa.europa.eu/documents/10162/13580/evaluation_pbt_vpvb_substances_seac_en.pdf/af4a7207-f7ad-4ef3-ac68-685f70ab2db3

[184] The wide variance of the range is primarily due to the significant uncertainty associated with the quantification of some costs and benefits. For instance, a saving could be achieved if the benefits in terms of reduced costs for clean-up and fire-water-run-off treatment are at the higher end of their estimated ranges and the costs in terms of disposal of stocks, cleaning of equipment, replacement of foam stocks are at the lower end of their estimated ranges, and vice-versa for the highest possible emission reduction costs per kg.

impacts of that transition. Therefore, it may be appropriate for regulatory management to set different conditions for the different sectors and applications, in order to balance the effectiveness of the measure with considerations around feasibility of alternatives and socio-economic impacts.

Table 9.3 summarises and compares substitution potential, socio-economic impacts and PFAS risk reduction potential across the main identified user sectors. Testing and training (across all sectors) are included separately because they vary significantly from application in actual fire incidents. The rows for user sectors refer to the use in actual fire incidents. Value judgements ("low", "high" etc.) are relative, based on a comparison between the different sectors and applications. A higher substitution potential, lower socio-economic impacts and a higher risk profile would suggest that stricter conditions can be imposed on the use/application in question, and vice versa. Conclusions are drawn below the table.

Table 9.3 Comparison of substitution potential, socio-economic impacts and PFAS risk reduction potential of different user sectors and applications

Use / application	Substitution potential	Potential socio-economic impacts	PFAS risk reduction potential
Chemical / petrochemical	**Low for some applications, medium/high for others:** Sector includes many different and complex scenarios. Alternatives have successfully been implemented for some applications but may not be readily available for others. In particular, additional testing required to confirm feasibility of alternatives for large atmospheric storage tanks.	**High:** By far the largest user (59% of annual sales), so transition is large scale. Highest potential fire-safety risks from using alternatives, although relatively low risk of danger to human life.	**High:** By far the largest user (59% of annual sales), average potential for retention of run-off and clean-up after incidents.
Marine Applications	**High:** Feasible alternatives considered to be available and have successfully been implemented by many users.	**Medium:** Average user (12% of annual sales), average potential for fire-safety risks from using alternatives.	**Very high:** Average user (12% of annual sales), likely lowest potential for retention of run-off and clean-up after incidents.
Military	**Medium:** Feasible alternatives considered to be available but not many have been certified or implemented by users yet.	**Medium/High:** Relatively small user (6% of annual sales), so relatively small scale of transition. Average potential for fire-safety risks from using alternatives, which could result in a relatively high potential of danger to human life.	**Medium:** Relatively small user (6% of annual sales), average potential for retention of run-off and clean-up after incidents.
Civil Aviation	**High:** Feasible alternatives considered to be available and have successfully been implemented by many users.	**Medium/High:** Relatively small user (9% of annual sales), so relatively small scale of transition. Average potential for fire-safety risks from using alternatives, but any risks would result in a relatively high potential of danger to human life.	**Medium:** Relatively small user (9% of annual sales), average potential for retention of run-off and clean-up after incidents.
Municipal Fire Services	**High:** Feasible alternatives considered to be available and have successfully been implemented by many users.	**Low:** Average user (12% of annual sales), so average scale of transition. Low potential for fire-safety risks from using alternatives.	**High:** Average user (12% of annual sales), likely lower potential for retention of run-off and clean-up after incidents because not restricted to specific industrial sites.

Use / application	Substitution potential	Potential socio-economic impacts	PFAS risk reduction potential
Ready to use applications	**High:** Feasible alternatives considered to be available. They have not yet been implemented by many users but ready to use applications rarely deal with large flammable liquid fires, so there is very little need for high performance foams.	**Low/Medium:** Relatively small user in terms of quantities (1% of annual sales according to Eurofeu data, several % based on estimated number of all fire-extinguishers) but potentially large number of devices affected (including millions of fire extinguishers). Very low potential for fire-safety risks from using alternatives.	**Medium/High:** Relatively small user, likely lower potential for retention of run-off and clean-up after incidents because not restricted to specific industrial sites.
Testing	**Very high:** Feasible alternatives considered to be available and have successfully been implemented by many users. No need for high performance foams.	**Very low:** Likely very small share of use, not the most expensive high performance foams required. Very low risk of damages resulting from performance of alternatives.	**Low:** Likely very small share of use, relatively high potential for retention.
Training	**Very high:** Feasible alternatives considered to be available and have successfully been implemented by many users. Little need for high performance foams.	**Low:** Likely very large share of use, but likely not the most expensive high performance foams required. Low risk of damages resulting from performance of alternatives.	**Low/Medium:** Likely very large share of use, but relatively high potential for retention.

The comparison in the table suggests that **training and testing should be the highest priority for a quick transition** to fluorine-free foams, because the use of alternatives is well established and already recommended as industry best practice. Training accounts for the majority of fire-fighting foam use (although likely not for the majority of emissions) and the potential for adverse socio-economic impacts is very low for training and testing.

Chemical / petrochemical are the largest user sector meaning that the costs of transitioning but also the current risk of PFAS emissions are higher. However, **derogations with a longer transition period may be needed for specific applications (notably large tank fires)** where the substitution potential is currently low (further testing is required to determine the technical feasibility of alternatives) and potential fire-safety risks from using alternatives are high. In these specific cases the socio-economic implications could outweigh the potential benefits in terms of PFAS emissions until more suitable alternatives have been developed and tested. Note that further testing on the feasibility of alternatives is planned by LASTFIRE[185] between April and July 2020 (although this may well be postponed due to the COVID-19 pandemic).

A **quick transition in marine applications should be a high priority** due to its low potential for retention of run-off and clean-up after incidents, and established alternatives.

Municipal fire services and ready to use applications should also be priorities for a quick transition because alternatives are well-established and these sectors may involve fire incidents outside of specific industrial sites where there is a risk that retention of run-off and clean-up after incidents are more difficult.

Alternatives are less well established in the **military sector**, but they are considered to be feasible by stakeholders and the applications are similar to those of other similar sectors (with similar activities such as aerospace), where substitution has taken place. **Transition is probably possible but requires extra care**

[185] A project by the oil and petrochemical industries to assess fire hazards of Large Atmospheric Storage Tanks (see www.lastfire.co.uk).

because if the use of alternative caused any fire-safety risks, the potential damages could be significant and could include danger to human life.

Also in **civil aviation** there is the concern that if the use of alternative caused any fire-safety risks, the potential damages could be significant and would likely include danger to human life. However, alternatives are considered feasible and have successfully been implemented by many users (e.g. the airports of Dubai, Dortmund, Stuttgart, London Heathrow, Manchester, Copenhagen, Australia and Auckland), so this is considered unlikely and a relatively quick transition should be sought, as has been achieved elsewhere.

Transition periods recommended for the various sectors are further discussed in the following section.

Transition periods

Several users have provided input on manageable transition periods:

- One stakeholder claimed that a transition time of **10 years** would be needed for the switch in the **O&G / petrochemicals** sector. Another stakeholder from the same sector cited **5-10 years**, in order to minimise and spread the costs to change foam and re-build, or re-place fire extinguishing systems or equipment, but they would like to keep PFAS stocks in case of a big fire incident. As reported in the case study in Section 7.6, Equinor took around 8 years to transition to fluorine-free foams;
- An industrial end user under consideration of discussions with some representatives from aviation industry groups and municipal users has developed a detailed draft proposed timeline covering a range of tasks required for a full transition to fluorine-free foams (across all sectors). The full timeline is provided in Appendix 4, but key milestones suggested are (years from formal start of transition and introduction of legislation):
  - No more PFAS foam use in **training: Immediately;**
  - No more PFAS foam use in **systems testing: 4 years;**
  - No more PFAS foams used for **small incidents: 4 years; and**
  - **Completion of transition: 10 years.** The additional 6 years from the previous steps is largely driven by further replacement and disposal of stocks of legacy foam[186], as well as the need for further development of fluorine-free foams by manufacturers.
- A stakeholder from the **aerospace and defence** sector suggested the system change to enable use of non-PFAS foam could be introduced at time of major refit, which typically occurs every **6 -12 years**. On the other hand, the US Fiscal Year 2020 National Defense Authorization Act (NDAA) requires a phase-out of PFAS-containing firefighting foam in the US military (except on ships) by October 2024, i.e. within **4 years**;
- Several stakeholders across different sectors stated at the workshop or in response to the written consultation that **3-6 years** may be sufficient;
- One stakeholder suggested **different transition periods for different uses**. They explained municipal fire brigades should be able to transition quicker than operators of fixed installations for example. They argued that the use of fluorine free foam for tank fire fighting needs further testing and therefore more time; and
- The PFHxA proposed restriction foresees the following transition periods: Concentrated fire-fighting foam mixtures placed on the market until 18 months after the entry into force of the restrictions can be used in the production of other firefighting foam mixtures until 5 years after

[186] Note that this does not necessarily imply that no more PFAS based foams are purchased during that period.

the entry into force, except for use of fire-fighting foam for training and (if not 100% contained) testing. There is also an exception proposed for concentrated fire-fighting foam mixtures for certain defence applications until a successful transition to alternatives can be achieved, and for concentrated fire-fighting foam mixtures for cases of class B fires in storage tanks with a surface area above 500 m^2 until 12 years after the entry into force.[187]

In conclusion, different transition periods have been considered appropriate for different uses. Successful transition to fluorine-free foams for training and testing has been reported by stakeholders across sectors and is already recommended as industry best practice. Therefore, a **transition period may not be required for training and testing**. In terms of the use for real fire incidents, **oil and gas / petrochemicals** are the only sector where users have suggested a longer transition period of **up to 10 years** is required, to conduct further testing of the feasibility of alternatives for large atmospheric storage tanks (LAST), among other things. This is broadly consistent with the reported duration of the transition by Norwegian oil and gas company Equinor (see case study 2 in Section 7.6), which took about 8 years from development and testing to full operation of fluorine-free alternatives. Oil and gas / petrochemicals is the largest user sector, so in order to ensure effectiveness of the regulation in reducing PFAS-emissions, the transition period should be limited to the most sensitive applications within this sector, particularly large incidents and LAST. For **small incidents as well as all other sectors** (e.g. marine applications, military, civil aviation, municipal fire services, ready to use applications), shorter transition periods between **3-6 years** have been suggested and are expected to minimise socio-economic implications of the restriction.

Concentration thresholds

There are two main considerations to choose appropriate thresholds for remaining PFAS-contamination in fire-fighting foams: The costs of cleaning and replacement of equipment which are strongly dependent on the concentration threshold chosen, and detection limits.

Costs of cleaning and achievable/detectable concentrations are discussed in more detail in Section 10.2 (sub-section a. Cleaning of equipment), but key messages are summarised below. The following thresholds were considered feasible by consulted stakeholders (all have been converted to ppb):

- Regulation in Queensland (Australia) allows up to **10,000 ppb** for PFOA/PFHxS and **50,000 ppb** for PFOA and PFOA related precursors and higher homologues. One stakeholder recommended these to be adopted in the EU as well;
- One stakeholder that has transitioned to fluorine-free foams (in the petrochemicals sector) reported that they had aimed for and achieved a level of 0.001% (**10,000 ppb**);
- One stakeholder reported experience with a relatively simple cleaning process (emptied tank, flushed two times with warm water) which can lead to very low remaining PFAS contamination (both when tested immediately and after a few years), but cautions a threshold below **100 ppb** would be unrealistic**;**
- Two stakeholders suggested **1 ppb** as the lowest achievable concentration in most cases. One of them linked this to a 32-stage legacy foam decontamination process costing €12,300 per appliance. In one-third of appliances this process can yield concentrations even lower (below 0.07ppb); and
- In terms of the lowest detectable concentrations, one stakeholder suggested laboratories are reported to be able to analyse down to a level of **30-150 ppb**. This is contradicted by other stakeholders that cite lower concentrations having been achieved and tested (see above). In the REACH restriction on PFOA, a concentration limit of **25 ppb** of PFOA including its salts or **1,000**

[187] Note that these transition periods and exemptions may change when (and if) the proposal is taken forward.

ppb of one or a combination of PFOA-related substances was adopted, based on the capabilities of analytical methods according to the RAC's opinion on the restriction dossier.

In conclusion, there was a wide divergence in opinion on appropriate concentration thresholds ranging from 1ppb to 50,000ppb. The available information suggests that **100 ppb can be achieved with a relatively simple cleaning process (cost likely low but not quantified) while 1 ppb is achievable with more complex and costly processes (in the order of €12,300 per appliance according to one estimate)**. Given this is based on a very small number of estimates, it appears advisable to seek further input on the costs of achieving a specific concentration in any consultation as part of a potential future restriction proposal.

Furthermore, a balance would need to be struck between the amount of PFAS emissions remaining if a given threshold is adopted, versus the costs of cleaning imposed in order to achieve that threshold. For example, if the concentration of PFAS in fluids in use is currently perhaps 0.5% (5 million ppb), a threshold of 100 ppb would represent a reduction in concentration (and hence emissions) of 99.998%, while a threshold of 50,000 ppb would represent a reduction in concentration and emissions of 99.0%.

Other risk management targeted at reducing release

Industry best practice guidance (e.g. from the Fire Fighting Foam Coalition[188]) and regulations or guidelines in some EU Member States (e.g. England and Wales[189], Bavaria[190]) already recommend or impose a range of measures to reduce the risk to the environment from the use of fire-fighting foams (see Section 9.4). These cover for instance containment, treatment, and proper disposal of foams and fire water run-off. However, it is not clear to what extent these practices are being implemented or what their relative effectiveness is.

Stakeholder input to the consultation has also highlighted the importance of such measures to reduce emissions of PFAS-based foams, with recommendations made to legally impose retention systems, proof of proper disposal of any contaminated water/liquid, and use of appropriate PPE and cleaning procedures for after-use treatment.

At the workshop, a stakeholder also suggested supporting the transition with mandatory fire management plans for every site, which would include a description of the procedure and reasons for the procurement of the specific fire-fighting foams, their storage, use, recovery, containment and treatment. They also proposed setting up centrally managed stocks at specific, well-contained sites in large industrial areas that could be made available to potential users in case of emergencies, in order to control and restrict the use of PFAS-based foams to only the necessary applications during the transition period. This suggestion could help reduce the risk to the environment while allowing a potentially longer period to transition to alternatives, particularly for large industrial sites.

In conclusion, it is advisable to further investigate a potential obligation to apply best practice emission reduction measures during and after the use of PFAS-based fire-fighting foam, particularly during the transition periods when PFAS-based foams continue to be used in certain applications and if the use of existing foams is not restricted (scenario 1).

9.7 Conclusions on the most appropriate (combination of) regulatory management options

Section 9.5 discussed the need for further regulatory management of the concerns associated with the use of PFAS in fire-fighting foams, based on the following:

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188 https://www.fffc.org/

189 Environmental Protection Handbook for the Fire and Rescue Service, https://www.ukfrs.com/sites/default/files/2017-09/Environment%20Agency%20and%20DCLG%20environmental%20handbook.pdf

190 https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/germany.htm

- Significant hazards have been shown at least for some PFAS, including some short-chain PFAS (not precluding any ongoing work or conclusions by the PFAS working group which were not available for this report);
- Many PFAS are highly mobile, highly persistent, and have the potential to accumulate within the environment and living organisms;
- The continued use of PFAS-based fire-fighting foams and resulting releases to the environment; and
- A lack of existing regulation, and of implementation or proven effectiveness of other risk management measures to address the release of PFAS from the use of PFAS-based fire-fighting foams.

It was agreed in discussions with the steering group to focus on assessing potential designs of a restriction, rather than comparing a restriction with alternative types of measures. However, a restriction appears to be an appropriate option because:

- Alternatives are considered feasible for most applications (all except large atmospheric storage tanks), so that PFAS emissions can be eliminated by using fluorine-free products; and
- Other risk management measures that could reduce release of PFAS to the environment are available and are to some extent already being applied; however, these appear unlikely to eliminate the emissions of PFAS from the use of fire-fighting foams as effectively.

It appears advisable to address the concern at EU-level, because there is no indication that Member State measures will be forthcoming, and any potential discrepancies in national-level management could have implications for the degree to which the environment is protected and for the functioning of the internal market for fire-fighting foam products. Furthermore, due to their high mobility and persistence as well as their ubiquity (at least of some PFAS), it appears very likely that PFAS emissions could lead to cross-border pollution.

Section 9.6 assessed the potential conditions of a restriction, in terms of whether it would ban only the placing on the market of PFAS-based fire-fighting foams, or both the placing on the market and the use of those foams. Potential variations across different user sectors, transition periods, concentration thresholds, and potential combination with other risk management measures are also relevant. Two main options have been considered:

- A **ban on the placing on the market** would allow continued use of existing stocks of PFAS-based fire-fighting foams, which have been estimated at between 210,000 and 435,000 tonnes. PFAS emissions related to their use could continue, and this may last for some 10-30 years after the entry into force of the restriction, based on the shelf-life of fire-fighting foams. When stocks are depleted, users would need to buy alternative foams incurring additional costs (compared to the baseline) of around €27m per year in the EU due to potentially higher volumes of alternative foams needed to achieve the desired performance. Before that, installations would need to be cleaned or replaced at potentially significant one-off cost (cleaning could potentially be in the order of up to €1 billion). This would be at least partly off-set by savings, e.g. from lower disposal cost of fire-water run-off (total difficult to quantify) and fluorine-free foams when they reach their expiry date (potentially €100,000s to € millions per year), and from reduced clean-up (potentially up to €10s of millions) / remediation costs (potentially up to € billions over a long time span). However, more information on the total number of sites, real-world use of PFAS per site as well as implementation and effectiveness of best practices in terms of containment and immediate clean-up would be required to assess the extent to which remediation and clean-up could be avoided by using fluorine-free fire-fighting foams. More details on uncertainties, ranges and other potential impacts are presented in Section 8.3; and

- A **ban on the placing on the market and the use** of PFAS-based fire-fighting foams would immediately stop the emissions from the use of PFAS-based fire-fighting foams. This increased effectiveness needs to be weighed against the additional socio-economic implications. The existing stocks of PFAS-based fire-fighting foams would need to be disposed of (incineration costs estimated at €320 million) and new stocks would need be purchased (subject to replacement costs minus the value of existing stocks already depreciated estimated at around €1 billion). Furthermore, roll-out by suppliers and training/familiarisation would need to be done in a much more compressed timescale, but any potential savings from using alternatives (as discussed above) would also be incurred more quickly.

It should be noted that these estimates are associated with significant uncertainties and ranges have been estimated. There are other potential economic costs and benefits that could not be quantified. Adjusting the potential restriction to minimise this is discussed further below.

Although alternatives are generally considered to be technically feasible in most applications (further testing is required for large atmospheric storage tanks), there are also potential implications of the performance of alternatives in some cases, including slower fire suppression, and foams being less flexible and less easy to use. These have not been quantified. It should be noted that there was divergence in the stakeholder input about technical feasibility of alternatives. A few stakeholders have voiced concerns over the potentially reduced fire safety, at least in specific applications, and the associated risk of additional health, safety and economic (fire damage) impacts. However our analysis has concluded that they are not the most likely outcome and that large atmospheric storage tanks are the main application for which there is still further testing required.

In order to maximise effectiveness while minimising potential adverse socio-economic impacts of a restriction, it appears appropriate to vary the specific conditions (particularly **transition periods**) by application and user sectors, because of their significant divergence in terms of the likelihood of emissions and implications of switching to alternative foams:

- **Training and testing** should be the highest priority for a quick transition to fluorine-free foams, because the use of alternatives is well established and already recommended as industry best practice. Training accounts for the majority of fire-fighting foam use (although likely not for the majority of PFAS emissions) and the potential for adverse socio-economic impacts is very low for training and testing;
- **Chemicals / petrochemicals** is the largest user sector meaning that the costs of transitioning but also the current risk of PFAS emissions are higher in total (although not necessarily higher per company, per turnover, etc.). However, derogations with a longer transition period may be needed for specific applications (notably large tank fires) where further testing is required to determine the technical feasibility of alternatives and potential fire-safety risks from using alternatives are high. Users have suggested a longer transition period of up to 10 years is required. This is the largest user sector, so in order to ensure effectiveness of the regulation in reducing PFAS-emissions, it seems appropriate that any longer transition period should be limited to the most sensitive applications within this sector, particularly large incidents and large atmospheric storage tanks. Further consideration of this would be needed in the (public) consultation on any restriction proposal;
- For **small incidents as well as all other sectors**, shorter transition periods between 3-6 years have been suggested and are expected to minimise socio-economic implications of a restriction:
  - Of these, in particular **marine applications, municipal fire services and ready to use applications** should be priorities for a quick transition. In marine applications the potential for retention of run-off and clean-up after incidents is particularly low, and alternatives are established. For municipal and ready to use applications, alternatives are well-established

and these sectors may involve fire incidents outside of specific industrial sites where there is a risk that retention of run-off and clean-up after incidents are more difficult;

- In **civil aviation** a relatively quick transition could be sought as well, because alternatives are considered feasible and have successfully been implemented by many users. However the potential for retention of run-off and clean-up is relatively high, while there is the concern that, if the use of alternatives caused any increased fire-safety risks, the potential damages could be significant and would likely include danger to human life; and
- Alternatives are less well established in the **military sector**, but they are considered by stakeholders to be feasible. Transition is probably possible but requires extra care because, if the use of alternatives caused any increased fire-safety risks, the potential damages could be significant and could include danger to human life. A relatively long transition period may be needed to allow for sufficient time for alternative products to gain the necessary certifications.

Regarding **concentration thresholds**, a balance would need to be struck between the amount of PFAS emissions remaining if a given threshold is adopted, versus the costs of cleaning imposed in order to achieve that threshold. Stakeholder input suggests that 100 ppb can be achieved with a relatively simple cleaning process (cost likely low but not quantified). Lower thresholds are achievable with more complex and costly processes. For instance, achieving 1 ppb could cost around €12,300 per appliance according to one estimate, which could imply EU total costs in the order of €1 billion. However, setting a lower concentration threshold would lead to a relatively small additional reduction in PFAS emissions, compared to the overall reduction achieved by the restriction. The average concentration of PFAS in PFAS-based fire-fighting foams is some 2-3%, mixed with water before application it is in the order of 0.5% (or 5 million ppb). This means a reduction from 5 million ppb to 100 ppb would cover 99.998% of the initial emissions. A further reduction to 1 ppb would cover 99.99998% of the initial emissions (an additional 0.00198%).

Lastly, it is advisable to further investigate a **potential obligation to apply best practice emission reduction measures** during and after the use of PFAS-based fire-fighting foam. These cover for instance containment, treatment, and proper disposal of foams and fire water run-off. Particularly during the transition periods when PFAS-based foams continue to be used in certain applications, and if the use of existing foams is not restricted, these measures could provide relatively effective reduction of PFAS-emissions at relatively low cost.

Appendix 1
Consultation questionnaire

The following questionnaire was sent directly via email to ~40 targeted stakeholders. The list of stakeholders was discussed with and approved by ECHA and the Commission prior to the launch of the consultation. The list of stakeholders aimed to target the full range of relevant sectors and backgrounds (see Section 2.1).

In a number of cases, stakeholders forwarded the consultation document to other stakeholders. In the scoping interview stage, it was agreed with the main European trade association for foam producers (EUROFEU), that they would provide a joint response for the manufacturers of foams. However, we also accepted submissions from individual producers.

A stakeholder contact log was maintained using an Excel file to keep a record of which stakeholders had received the consultation. A consultation period of ~6 weeks was allowed, for the completion of the stakeholder questionnaire. A brief extension to this time limit was permitted for a number of stakeholders, to maximise the number of responses received.

The responses to the consultation questionnaire were collated into an Excel table, to allow relative ease of comparison between the different inputs, and easily identify any key trends or discrepancies between the responses for each individual question/section of the survey.

Questionnaire: Consultation on polyfluoroalkyl and perfluoroalkyl substances (PFAS) in firefighting foams and on their alternatives

Introduction to this consultation

Wood Environment and Infrastructure Solutions UK Limited ('Wood') has been commissioned by the European Commission, DG Environment ('DG ENV') and by the European Chemicals Agency ('ECHA') to conduct two inter-connected projects to provide an assessment on polyfluoroalkyl and perfluoroalkyl substances (PFASs) in firefighting foams, covering:

- **"The use of PFAS and fluorine-free alternatives in fire-fighting foams" (the 'DG ENV study'); and**
- **"Assessment of alternatives to PFAS-containing fire-fighting foams and the socio-economic impacts of substitution" (the 'ECHA study').**

Wood is working in partnership with Ramboll on the DG ENV study and with COWI on the ECHA study, both acting as subcontractors to Wood.

The overall aim of these projects is to assess the use of PFAS and alternatives (including fluorine-free substances) in firefighting foams, including the identity and functionality of the substances used; volumes of firefighting foams on the market; the availability and technical and economic feasibility of alternatives; the releases to different environmental compartments; the environmental and health impacts; and remediation costs when the fire-fighting foams are released. **The ultimate goal is to identify the most appropriate instrument for possible regulatory risk management activities, either towards new foams products**

and/or those already used in existing systems, to address the concerns resulting from the use of PFAS in fire-fighting foams and assess the potential socio-economic impact of these activities.

Why have we have contacted you?

This survey is a key step in the data gathering process of these projects. It is essential for us to collect the relevant data and opinions, covering the full range of stakeholders involved in the production and use of firefighting foams, including manufacturers and users of foams across different sectors (e.g. aviation, oil and gas, chemicals), as well as remediation specialists, academia, national authorities and NGOs.

This questionnaire is addressed to you as a key stakeholder. We hope that you are able to complete as much as possible of the questionnaire using data already available or in the case of industry associations, based on a rapid survey of your member companies, given the available timescales.

Your response will help to ensure that the possible options for, and implications of, potential regulatory risk management measures for your sector or field of expertise are taken into account as the European Commission and ECHA consider this issue.

Confidentiality

We are aware that some of the information you may want to provide could be commercially sensitive and confidential. If any of the information provided is to be viewed as confidential, please clearly mark this as such and we will agree any further steps with you, including how to report any information derived from your confidential input to the European Commission or ECHA. We will not disclose any information marked as confidential without your permission to the Commission, ECHA or any third party.

We will make anonymous all information relevant to specific companies and/or facilities within our reporting and will not pass on the information that you provide to any other party without your express permission. Any information you provide will solely be used for the purpose of this study and provision of a report to the European Commission or ECHA. We will also present uncertainty ranges in reported data in order to avoid disclosing market-sensitive information.

This questionnaire

Please complete all of the questions that you are able to. The survey questions are split into separate sections covering:

- Background information on you and your organisation;
- Chemical identity, functionality of PFAS in firefighting foams;
- Alternatives to PFAS in firefighting foams;
- Foam use and environmental emissions;
- Implications of potential regulatory action; and
- Additional information – including suggestions for other resources and stakeholders to consult.

Where you are not able to answer questions in one or more of the sections – due to lack of data or because it is not relevant to your organisation – there is no need to provide a response. Where answers are uncertain, an estimate is more useful than no information at all. Where annual data is provided, please state the year.

Please return you completed questionnaire to us by **28 June 2019**.

Please be aware that if responses are received after this date, then the information may not be included in our analysis.

Project timeline

Upon closing the consultation in June 2019, we intend to use the information collected from this stage to inform the following stages of the project:

- A stakeholder workshop to be held in Helsinki on 24 September 2019. This will be used to discuss and validate the initial findings of the project(s) and gather additional evidence; and
- A final report to be delivered to ECHA and the European Commission in February 2020.

Contact details

Should you have any questions or require any further information, please do not hesitate to contact the project team:

Ian Keyte (Consultation Coordinator), +44 (0)20 3215 1868, ian.keyte@woodplc.com

Julius Kreißig (Project Manager, DG ENV study), +44 (0)20 3215 1671, julius.kreissig@woodplc.com

Liz Nicol (Project Manager, ECHA study), +44 (0)118 913 7354, liz.nicol@woodplc.com

Part 1: Background information

Your details

Name:	
Organisation:	
Job title:	
Telephone number:	
E-mail address:	
Type of organisation:	☐ Manufacturer ☐ User/Industry ☐ NGO ☐ Academic ☐ Member State Competent Authority / Agency ☐ Remediation ☐ Other If Other, please specify:
If 'user/ industry', which sector applies to you:	☐ Oil refineries/storage ☐ Chemicals ☐ Petrochemicals ☐ Airports ☐ Other (please specify):

Summary of activities of your organisation:	

Part 2: Chemical identity, functionality of PFAS in firefighting foams

This section aims to identify which PFAS are currently being used in which fire-fighting foam products, the function these PFAS impart on the foams and the volumes of these products that are currently on the market and used in the EU,

2.1. Identity of firefighting foam products in use

Please provide details of the firefighting foam products currently used in your sector(s) that intentionally use PFAS, or where PFAS are known to be present as impurities.

Please indicate the sector(s) in which these foams are used, and the typical application method used. If within their sector(s) of use, multiple different foam products are used, indicate the type and size of fire that specific product can be used for. Please also provide an indication of whether the product is produced in the EU, and if not, where it is imported from, and in what quantities.

If the product is currently on the market in the EU (i.e. it is being sold), please note the geographic scale to which your response refers (e.g. national, EU, global markets), and if no longer sold, please indicate if the foam product is still used in existing firefighting systems.

#	**Product name**	**Sector(s) applicable**	**Type of use**	**Application method**	**Produced in the EU?**	**Currently on the market in the EU?**
	e.g. trade name, brand	*e.g. airport, oil and gas, chemicals*	*e.g. the type and size of fire; training only?*	*e.g. fixed/mobile, Compressed Air Foam, etc.*	*Y/N (If N, please note the country imported from)*	*Y/N (If Y, at national, EU, global scale? If N, is the product still used in existing systems?)*
1						
2						
3						
4						
5						

(add additional rows if required)

2.2. Identity of PFAS used in firefighting foams

For each of the products described in Section 2.1, please provide details of the PFAS intentionally used, and where PFAS or other harmful chemicals are known to be present as impurities.

#	**PFAS used**	**Estimated PFAS content (w/w)**	**Known impurities**
	e.g. the chemical or common/ abbreviated name and CAS#	*e.g. the PFAS contained and the % composition by weight, if known*	*e.g. PFAS and other chemical impurities present; estimated % composition (w/w)*
1			
2			
3			
4			
5			

2.3. Volume of PFAS-containing firefighting foam concentrates

For each of the products described in Section 2.1, please provide an estimate of the total quantities of foam concentrates manufactured/imported and sold, the approximate revenue or unit price derived from their sale, and total quantities currently present in existing systems. <u>We are particularly interested in EU-level estimates, if these are available</u>. Please specify if the information provided is at company, sector, national or European level, depending on your role/organisation.

Please provide any available information on past trends or expected future changes in production and sales, and the drivers of these trends. Please specify the timescales covered by these trends. Ideally this should be limited to the previous 10 years.

#	Volume manufactured in the EU / imported to the EU	Volume sold in the EU	Revenue from product sales (or if not known, average unit price)	Volume present in existing systems in the EU	Trends in production/sales of product	Main drivers for changes
	e.g. annual production, import	*e.g. annual sales*	*e.g. Annual company turnover from product; unit price of products*	*e.g. quantity previously installed and not yet used/disposed of and therefore currently present in existing systems*	*e.g. trend over the previous 10 years and any expected future trends*	*e.g. costs, regulations, other market factors*
1						
2						
3						
4						
5						

(add additional rows if required)

2.4 Functionality of different components (e.g. film-forming, surfactants, solvents)

For each of the firefighting foam products described in Section 2.1, please describe the specific technical function that the PFAS provide to the foam, which specific applications/uses this function enables, and why PFAS have not been fully replaced by alternatives in this application.

#	Function of PFAS in the foam	Specific applications/uses this function enables	Why have foam products containing PFAS not been fully replaced by alternatives in this application?
	e.g. film-forming, surfactants, solvents, others	*e.g. effective control of 10m+ tank fires*	*e.g. consideration of costs, compliance with safety standards*
1			
2			
3			
4			
5			

(add additional rows if required)

Part 3: Alternatives to PFAS in firefighting foams

This section aims to identify the chemical substances/products being used in specific fire-fighting foams in place of PFAS, volumes on the market, and the implications of using these alternatives.

3.1 Alternative firefighting foam products

For firefighting foam concentrates containing PFAS, are any alternative PFAS-free firefighting foam products (including fluorine-free products) available that could potentially perform their functions and/or enable the same applications?

Please provide details of these products and, where applicable, which products described in Section 2.1 these are designed to replace in the table below. Please specify if the alternative foam is a direct 'drop in' replacement or if this can only partially substitute the PFAS foam, and under which conditions

#	Product name	Sector(s) applicable	Type of use	Application method	Is this product a substitute for the foams detailed in Section 2.1 (please refer to the number(s) of the product(s) listed under Section 2.1. applicable)?*
	e.g. trade name, brand	*e.g. airport, oil and gas, chemicals*	*e.g. the type and size of fire; training only?*	*e.g. fixed/mobile, Compressed Air Foam, etc.*	*e.g. is this a direct drop-in replacement or used in combination with other products; under which conditions? (Note that the differences in technical performance will be discussed in Section 3.5)*
A					
B					
C					
D					
E					

(add additional rows if required)

3.2 Chemical identity of alternatives

For the alternative firefighting foam concentrates products described in Section 3.1. Please provide details of the main chemical constituents, both those used intentionally in the formulation, and those potentially present as impurities.

#	**Key chemical composition**	**PFAS present as impurities?**
	e.g. chemical constituents and their proportions w/w	*e.g. approx. % concentration w/w*
A		
B		
C		
D		
E		

(add additional rows if required)

3.3 Availability of alternatives

Please provide details on the availability of the alternative foams described in Section 3.1 and 3.2.

Please indicate if these products are produced in the EU (or the country imported from), and if these are currently available on the market and in use. For products that are being developed/not yet available, please provide an indication of the amount of time expected for these to reach the market in the necessary quantities to replace the PFAS-containing foams.

#	**Produced in the EU?**	**Currently on the market in the EU?**	**Reasons why product is not currently on the market**	**Estimated timescale for product reaching the market.**
	Y/N, (if N, please note the country imported from)	*Y/N, (e.g. at national, EU, global scale?)*	*e.g. still in R+D phase, awaiting approvals, phased out due to environmental concerns*	*e.g. approx. number of months/years if known*
A				
B				
C				
D				
E				

(add additional rows if required)

3.4 Volume of alternative firefighting foam concentrates

For each of the products described in Section 3.1, please provide an estimate of the total quantities of foams manufactured/imported and sold, and the approximate revenue or unit price derived from their sales. We are particularly interested in EU-level estimates, if these are available.

Please specify if this information is at company, sector, national or European level, depending on your role/organisation.

#	**Volume manufactured in the EU / imported to the EU**	**Volume sold in the EU**	**Revenue from product sales (or if not known, average unit price)**	**Trends in production/sales of product**	**Main drivers for changes**
	e.g. annual production, import	*e.g. annual sales*	*e.g. Annual company turnover from product; unit price of product*	*e.g. trend over the previous 10 years and any expected future trends*	*e.g. costs, regulations, other market factors*
A					
B					
C					
D					
E					

(add additional rows if required)

3.5 Technical feasibility of alternatives

Where alternative foams are being developed or are marketed, please provide details any technical implications of using those alternatives, compared with 'traditional' PFAS-containing foams they were designed to replace.

Technical implications of alternatives

For the alternative products described in Section 3.1, please provide an indication of any technical implications associated with using these alternatives relative to the PFAs-containing foams. For example, do they impart the desired functionality and comply with the required performance criteria/standards; are there differences in required volumes of use or application methods? Please provide an indication of whether the alternative can only partially replace the PFAS-containing foam, and the reasons why.

# *Please refer to products in Section 3.1*	**Application/use compared to PFAS-containing foams (add the corresponding the foam detailed in Section 2.1)**	**Compliance with performance standards**	**Differences in volumes required between different foams to achieve comparable/ acceptable functionality**	**Other implications (e.g. different application method, equipment needed)**
	Can the alternative replace the use of the PFAS foam entirely, and if not, how does it differ? Specify if the alternative foam can only partially substitute the PFAS foam.	*Which standards are the foams in compliance?*	*e.g. per application or total volume used per year*	*Please specify*
A				
B				
C				
D				
E				

(*add additional rows if required*)

Comment on feasibility of the foams for different uses and applications

Please provide an indication, in your opinion, of whether the alternative foam products are technically feasible of replacing PFAS-containing foams, and why. Please also highlight any specific applications or uses where these alternatives ARE, or are NOT considered feasible alternatives.

# ***(please refer to products in Section 3.1)***	**Overall, do you consider the alternative as technically feasible for this specific application/use?**	**Uses/applications where alternatives ARE considered technically feasible**	**Uses/applications where alternatives are NOT considered technically feasible**
	e.g. Y/N, please explain	*e.g. types or scale of fire or use in particular situations or equipment*	*e.g. types or scale of fire or use in particular situations or equipment*
A			
B			
C			
D			
E			

(*add additional rows if required*)

Critical uses/applications

Are there critical uses/applications of fire-fighting foams where PFAS CANNOT be adequately replaced by ANY alternatives? If yes, please substantiate your statement.

3.6 Economic feasibility of alternatives

Based on the available information, what are the financial/economic implications of using those potential alternatives? For example, where detailed testing results of fire extinguishing systems are available, please provide details of these and indicate if/where this is confidential information.

For the alternative foams detailed in Section 3.1, please complete the tables below on the potential costs; savings; and other financial implications.

Costs

# (please refer to products in Section 3.1)	**Unit price of alternative product**	**Required amounts/loadings of alternative foams**	**Frequency of foam replacement**	**Costs of new equipment required**
	e.g. or unit price differences between PFAS-based foams and 'alternatives'	*e.g. required to achieve comparable/ acceptable functionality*	*e.g. due to expiration date*	*e.g., capital cost of purchase and installation, operational cost compared to previous equipment*
A				
B				
C				
D				
E				

Savings

# ***(please refer to products in Section 3.1)***	**Savings from the use of the alternative foam** *e.g. avoided clean-up and/or remediation costs*
A	
B	
C	
D	
E	

Other financial aspects

# ***(please refer to products in Section 3.1)***	**Other financial aspects**
A	
B	
C	
D	
E	

(*add additional rows if required*)

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Part 4: Foam use and environmental emissions

This section is aimed at identifying the quantities of fire-fighting foam products used, disposed of and potentially released to the environment.

4.1 Firefighting foam use

If you are a user of firefighting foams, for the foam products identified in Sections 2.1 and 3.1, please provide information (quantitative if possible) on the volumes of foam purchased and used per year (including both products based on PFAS and fluorine-free alternatives). If available, please provide any information on the volumes used in each instance of foam use.

PFAS-containing firefighting foams

#	**Amount of foam purchased per year**	**Volume of foams per instance of use**	**Typical frequency of use**	**Additional detail on this sector/use**
	kg/year	*kg. Please specify if concentrate or water-added solution*	*minutes, hours etc*	*describe typical application practices*
1				
2				
3				
4				
5				

(*add additional rows if required*)

PFAS-free alternatives

#	Amount of foam purchased per year	Volume of foams per instance of use	Typical frequency of use	Additional detail on this sector/use
	kg/year	*kg. Please specify if concentrate or water-added solution*	*minutes, hours etc.*	*describe typical application practices*
A				
B				
C				
D				
E				

(*add additional rows if required*)

4.2 Firefighting foam collection and prevention of release to the environment

Please provide information on any measures, both in terms of legislation and best practice actions, put in place to prevent release of firefighting foam discharges to the environment. If available, please indicate if the level of implementation of these measures has been monitored or assessed.

Is there national-level legislation in your Member State governing the containment/prevention of release of firefighting foam/ firewater runoff to the environment?

Y/N	If Y, please provide details
	e.g. what the legislation controls, how it is implemented and enforced.

Is there best-practice guidance available to users on how to best contain/prevent release of firewater and foam discharge to the environment?

Y/N	If Y, please provide details	What level of implementation for these best practice measures is currently achieved?
	e.g. who published the guidance, what does this cover?	*e.g. number/proportion of installations with action plans in place for minimising discharges, with specialised equipment in place, etc*

If possible, please provide information (quantitative if possible) on the quantities or proportions of foams sent for different disposal practices. Please complete the following tables for PFAS-containing foams and alternative foams.

PFAS-containing firefighting foams

#	**Volume/% collected** *(Please specify if you refer to concentrate or water-added solution)*		**Volume/% not collected (i.e. potentially released to the environment)** *Please specify if you refer to concentrate or water-added solution*	**Other disposal options used**	**Additional detail on this disposal** *e.g. reason, conditions such as temperature and incineration time*
	For incineration	**For other disposal/ treatment**			
1					
2					
3					

4					
5					

(*add additional rows if required*)

PFAS-free alternatives

#	**Volume/% collected** (*Please specify if you refer to concentrate or water-added solution)*		**Volume/% not collected (i.e. potentially released to the environment)** *Please specify if you refer to concentrate or water-added solution*	**Other disposal options used**	**Additional detail on this disposal** *e.g. reason, conditions such as temperature and incineration time*
	For incineration	**For other disposal/ treatment**			
A					
B					
C					
D					
E					

(*add additional rows if required*)

4.3 Disposal of foams

For the foams and uses described under 2.1 and 3.1, if applicable, please provide information (quantitative or qualitative) on the disposal practices used (e.g. incineration or waste water treatment practices).

Please indicate the type and conditions of the processes used and the associated costs, either per unit weight of foam disposed, or total operations costs if available. Please provide any available information on the environmental emissions, particularly the chemical identity and concentration of any fluorinated substances released.

Is there sufficient capacity available to dispose of waste firefighting foams in your facility/country?

# *see Sections 2.1 and 3.1*	**Type of disposal**	**Conditions used**	**Estimated costs**	**Environmental emissions**	**Sufficient capacity available for disposal?**
	e.g. hazardous waste incineration; municipal waste incineration	*e.g. temperature; time*	*e.g. cost per kg of foam; total operating costs per year*	*e.g. type and concentration of fluorinated substances*	*e.g. Y/N ; please explain*

(add additional rows if required)

4.4 Environmental releases

For the foams and uses described under 2.1 and 3.1, please provide information (quantitative or qualitative) of the expected or actual environmental discharges of PFAS and/or fluorine-free chemicals used in firefighting foams to the environment.

Please include any known information on the volumes of release, the particular circumstances or activities leading to release:

Product # *see Sections 2.1 and 3.1*	**Discharge to terrestrial environment**	**Discharge to surface water**	**Discharge to ground water**	**Additional detail on this discharge**
	e.g. typical share of product used, total quantity	*e.g. typical share of product used, total quantity*	*e.g. typical share of product used, total quantity*	*e.g. description of the circumstances of the release or any other explanations of the data provided*

Part 5: Potential restrictions on PFAS in firefighting foams

5.1 Impacts of a potential restriction

Are there any other key impacts (other than already mentioned under economic feasibility of alternatives) in the event of a restriction on PFAS-containing firefighting foams for your sector that you would like to point out?

Such impacts could include those associated with the performance of the sector using firefighting foams (e.g. increased safety risk at airports), impacts on manufacturers of firefighting foams (e.g. impacts on employment), the impacts on trade and competitiveness, and those associated with the improved protection of human health and the environment through reduced exposure to PFAS.

Please provide details, along with any supporting quantitative and/or qualitative estimates if possible, on the following aspects:

Potential impact of different transition periods for phasing out PFAS in firefighting foams? (e.g. in relation with the ability to use the PFAS foams already in stock and the expiry date of foams in stock).

Potential impact of different threshold concentrations of PFAS (i.e. impurity levels) in firefighting foams once the potential future regulation is in place? (e.g. in relation with the cost to clean up the installation to comply with the PFAS impurity threshold)

Potential impact of restrictions on new PFAS-containing firefighting foam products entering the market only vs restrictions on both new PFAS-containing foam products and those already in use in existing systems?

Part 6: Additional information

6.1 Other information

If there is any other information you would like us to take into account, please provide details here:

If you wish to submit documents directly, please provide these as an email attachment accompanying this completed questionnaire. Please clearly label any attachments as 'non-confidential' (preferred) or 'confidential' to ensure we handle any information provided appropriately.

6.2 Suggestions for additional resources to consult

Please provide the details or links to any other useful resources/literature that provide information on any of the key aspects of the project covered in this survey

Reference	**Link**	**Details**

(*add additional rows if required*)

Thank you very much for completing this questionnaire. We appreciate you taking the time to help with this project.

Appendix 2
Workshop report

Appendix 3
Overview of PFAS physical properties and why they contribute to hazards

FAS is a term used to cover approximately 4,700 specific chemical species[191]. Longer chain (≥ C8) PFAS compounds have been used within industry as surfactants specifically because of their potent water and oil repellence at low concentrations (Buck, 2011). Prior to 2000 the use of PFAS within fire-fighting foams in Europe utilised the salts of C8 PFAS compounds such as PFOS and PFOA, particularly the ammonium salt of PFOA (APFO) (CAS 3825-26-1)[192].

As of the late 1990s growing concerns around longer chain PFAS compounds highlighted that they were highly mobile in the aquatic and terrestrial environment, highly persistent, and had the capability to bioaccumulate up food chains[193]. Many longer chain PFAS species also had toxic effects identified. The ECHA SVHC nomination dossier for PFOA (2013) indicated that PFOA (from the ammonium salt) is readily absorbed by the body and can pass to the foetus (by blood) and child (by mother's milk), and concentrates in the blood, liver and kidneys with toxic effects. The nomination also notes that the RAC identified sufficient scientific evidence to conclude that PFOA could also be a reproductive toxin for the unborn child.

Concerns over the mobility and persistence of longer chain PFAS substances, along with potential health effects led to an industry initiative in the early to mid-2000s to switch to shorter chain (≤ C6) PFAS alternatives (UNECE, 2004). For fire-fighting foams this includes the salts of C6 or lower based PFAS substances[194]. However, concerns have continued that shorter chain PFAS substance are also mobile (if not more mobile) than ≥C8 substances and are highly persistent albeit with potentially lower bioaccumulation[195].

Table A3.1 provides as an example of the mobility of PFAS compounds with different carbon chain lengths (based on log Koc) as an indicator that shorter chain PFAS are likely to be highly mobile. Kjolholt (2015)[196] indicates that WWTPs are likely to be ineffective against short-chain PFAS, just as they are also ineffective against longer chain PFAS compounds.

[191] OECD, 2018, PFAS database, toward a new comprehensive global database of per and polyfluoroalkyl substances.
[192] Stockholm Convention risk management evaluation dossier for PFOA, its salts and related compounds UNEP/POPs/POPRC.14/6/Add.2
[193] UNECE, 2004, PFOS dossier for purpose of nominating PFOS to the LRTAP Protocol and Stockholm Convention.
[194] Tyco fire protection, 2016, 'Transition if the firefighting foam industry from C8 to C6 fluorochemistry'.
[195] Cousins et al, 2018, 'short-chain perfluoroalkyl acids: environmental concerns and regulatory strategy under REACH', Environmental science Europe vol 30.
[196] Kjoltholt et al, 2015, 'short chain polyfluoroalkyl substances (PFAS) a literature review of information on human health effects and environmental fate and effect of short chain PFAS', Danish Ministry for Environment.

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Table A3.1 Overview of PFAS substances mobility using log Koc

Carbon chain length	Species	CAS number	Log Koc
PFCAs			
11	Perfluoroundecanoate (PFUnDA)	2058-94-8	3.3 to 3.56
10	Perfluorodecanoate (PFDA)	335-76-2 // 3830-45-3 // 3108-42-7	2.76 to 2.96
9	Perfluorononanoate (PFNA)	375-95-1	2.36 to 3.69
8	Perfluorooctanoate(PFOA)	335-67-1	1.89 to 2.63
8	Perfluorooctane sulfonate (PFOS)	1763-23-1	2.4 to 3.7
6	Perfluoroheptane sulfonate (PFHxS)	355-46-4	2.4 to 3.1
6.1	Perfluorohexanoate (PFHxA)	307-24-4	1.3
4	Perfluorobutane sulfonate (PFBS)	375-73-5 // 59933-66-3	1.2 to 1.79
4	Perfluorobutanoate (PFBA)	375-22-4	1.9
Fluorotelomers			
8	8:2 Fluorotelomer alcohol (8:2 FTOH)	678-39-7	4.13
6	6:2 Fluorotelomer alcohol (6:2 FTOH)	647-42-7	2.43
4	4:2 Fluorotelomer alcohol (4:2 FTOH)	2043-47-2	0.93

*reference ITRCP PFAS factsheet. https://pfas-1.itrcweb.org/

Appendix 4
Detailed foam transition timescales (from industry)

The following table has been provided as stakeholder input by an industrial end user and is reproduced in this report with kind permission from that stakeholder. Note that the table reflects the views of that stakeholder. Conclusions of the authors of this study are presented in the main body of the report.

Key

- Research/Testing
- Modification to Standards, legislation etc
- Development of Guidance/data gathering
- Site Specific Tasks
- Other
- Milestones

Task	Notes	t-4	t-3	t-2	t-1	T	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Formal Start of Transition and Introduction of Legislation	Assumed start date. If delayed, then subsequent phases would be delayed also															
Manufacturer development of FF products	Ongoing/continuous															
Validation of performance based small scale acceptance testing - tanks	Already done by LASTFIRE for tanks, using conventional application methods															
Validation of performance based small scale acceptance testing - aviation	Some work done by aviation authorities but needs greater full acceptance.															
Validation of performance based small scale acceptance testing - general purpose use (municipal brigades)	Effectively already completed as EN 1568 performance based															

Task	Notes	t-4	t-3	t-2	t-1	T	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Establishment of formulations and effects of different foam types	PERF work in progress for oil industry, but relevant to all sectors															
Acceptability criteria for PFAS, etc	By regulator															
Full environmental effects data for new concentrates and acceptability criteria	Regulator needs to be precise on requirements so that foams can be tested before introduction of legislation															
Small Scale Testing and selected large scale testing with a range of fuels including water soluble.	LASTFIRE is about to embark on this sort of programme working with German Industrial Firefighters et al.															
Large scale testing of proven foam concentrates and monitor application to deep seated (deep fuel) fires	Planning this with GESIP and others															
Approvals Listings	Critical in some areas globally and in some industries															
Modification of standards and system design/acceptance criteria	LASTFIRE working with NFPA and EN EN strictly already in place as EN 13565 refers back to EN 1568 performance criteria NFPA requires further work															
Stop using PFAS foams in training																
No more PFAS foams used in training																
Stop using PFAS foams in system testing or, if PFAS is still in place ensure total containment and appropriate treatment	Every effort should be made to minimise the need for discharging PFAS based foams in system testing, even when full containment is available															
No more PFAS foams used in system testing																

Task	Notes	t-4	t-3	t-2	t-1	T	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Review and revision of site ERPs including containment issues	Suggest this should be a requirement early on in transition to minimise current usage															
Replacement of stocks with FF																
Development of company/site long term plan for transition	We suggest this should be a regulatory requirement on a site specific basis															
Development of site programme/instructions to control stocks and use of PFAS foams, risk assessments, control/mitigation measures, containment and collection, disposal etc.																
Completion of Site Specific Transition Plans	Should include milestones and reporting															
Development and acceptance of alternative technology options using Fluorine Free Foam with appropriate testing	LASTFIRE ongoing programmes with CAF, Sef Expanding Foam, Hybrid Medium Expansion, etc.															
Development of guidance on proven and accepted methods of cleaning foam tanks and equipment																
Development of guidance on appropriate disposal routes																
Management of change evaluation and programme to ensure compatibility and effectiveness of every foam system	Companies are already beginning to evaluate this recognising the current situation															
Transition to Fluorine Free for first strike application to small incidents																
No more PFAS foams used for small incidents																
Full corrosion and materials compatibility data of new concentrates	See LASTFIRE Typical procurement specification															

Task	Notes	t-4	t-3	t-2	t-1	T	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Testing of compatibility of applying different foams to an incident simultaneously																
Compatibility of concentrates data	Not good practice to mix concentrates anyway, but perhaps useful for commercial reasons															
Agreement of accepted disposal routes																
Fire testing with site specific fuels and equipment																
Roll out of site management of change programme/instructions																
Disposal of existing concentrates																
Possible development and management of interim strategic stock holdings	Although no formal plans, an option to still have current foams available if there are concerns might be for industry to develop strategic, well managed and controlled stock for major incidents. This would have to include plans for containment and immediate clean up if the stock was to be used.															
Completion of Transition																

Appendix 5
List of international standards for fire-fighting foam performance

International Fire-fighting Foam Standards	Underwriters Laboratory	International Civil Aviation Organization			EN 1568			
	UL162	ICAO Level A	ICAO Level B	ICAO Level C	Part 1	Part 2	Part 3	Part 4
Description	UL 162 is an Internationally recognised test method carried out by the UL (Underwriters Laboratory), an independent not-for-profit organisation.	In the UK, the CAA (Civil Aviation Authority) requires a foam concentrate for use in Civilian Airports to be tested using potable (fresh) water to ICAO Level A, B or C.			European Standard that critically tests a foam for both extinguishment and burnback in sea and potable (fresh) water			
Sector(s) applicable	Offshore platforms	Onshore Civilian Airports	Onshore Civilian Airports	Onshore Civilian Airports	All	All	All	All
Type(s) of fire / fuel	Heptane fire, or polar solvent	Heptane fire	Heptane fire	Heptane fire	Heptane fire	Heptane fire	Heptane fire	Acetone fire
Type(s) of foam	All	All	All	All	Medium expansion foam for use on water-immiscible liquids	High expansion foam for use on water-immiscible liquids	Low expansion foam for use on water-immiscible liquids	Low expansion foam for use on water-miscible liquids
Area applicable	50 sq. feet	2.8m^2	4.5m^2	7.32m^2	4.52 m^2	4.52 m^2	4.52 m^2	1.72 m^2

International Fire-fighting Foam Standards	Underwriters Laboratory	International Civil Aviation Organization			EN 1568			
	UL162	ICAO Level A	ICAO Level B	ICAO Level C	Part 1	Part 2	Part 3	Part 4
Application conditions	Using a freeze protected foam with potable (fresh) and sea water	Foam concentrate for use in Civilian Airports to be tested using potable (fresh) water	Foam concentrate for use in Civilian Airports to be tested using potable (fresh) water	Foam concentrate for use in Civilian Airports to be tested using potable (fresh) water				
Application Rate (L/min/m2)	1.63	4.1	2.5	1.75	2.52L/min/m^2	2.52L/min/m^2	2.52L/min/m^2	6.6L/min/m^2
Discharge Rate (L/min) and duration	18.6 (180 s)	11.4 (120 seconds)	11.4 (120 seconds)	11.4 (120 seconds)				
Extinguring time (with flickers)		<60 seconds	<60 seconds	<60 seconds				
Extinguishing time (full)	<180 seconds	<120 seconds	<120 seconds	<120 seconds				
Pre-burn time	60 seconds	60 seconds	60 seconds	60 seconds	60 seconds	60 seconds	60 seconds	120 seconds
Burnback test (and waiting time)	Yes (20% in 300 seconds); 540 seconds	Yes, 2 minutes	Yes, 2 minutes	Yes, 2 minutes				

International Fire-fighting Foam Standards	Underwriters Laboratory	International Civil Aviation Organization			EN 1568			
	UL162	ICAO Level A	ICAO Level B	ICAO Level C	Part 1	Part 2	Part 3	Part 4
20% Re-ignition Time (mins)		>5	>5	>5				
Nozzle type	Hose nozzles, monitors	“Uni 86” Foam Nozzle"	“Uni 86” Foam Nozzle"	“Uni 86” Foam Nozzle"	“Uni 86” Foam Nozzle"	“Uni 86” Foam Nozzle"	“Uni 86” Foam Nozzle"	“Uni 86” Foam Nozzle"
Nozzle pressure (Kpa)	Not specified	700	700	700				
Degradation considered	No	No	No	No				
Pass/Fail test?	Yes	No	No	No	Not a pass or fail standard	Not a pass or fail standard	Concentrates are allocated grades of performance, ie Grade 1-4 for extinguishing performance and Grades A-D for burnback resistance. 1A is the highest achievable grade	Concentrates are allocated grades of performance, ie Grade 1-2 for extinguishing performance and Grades A-C for burnback resistance. 1A is the highest achievable grade

International Fire-fighting Foam Standards	Underwriters Laboratory	International Civil Aviation Organization			EN 1568			
	UL162	ICAO Level A	ICAO Level B	ICAO Level C	Part 1	Part 2	Part 3	Part 4
Frequency of monitoring/ conformity testing	3 months	N/A	N/A	N/A				
Sea water or powder compatibility	Sea water	No test protocol provided	No test protocol provided	No test protocol provided				

	International Maritime Organization		CAP 437	Military Specification (US)	National Fire Protection Agency (NFPA)	ISO - 7203			
	IMO MSC.1/Circ.1 312	**IMO MSC Circ.670**	**CAP 437**	**MIL-F-24385**	**NFPA 11**	**7203-1**	**7203-2**	**7203-3**	**7203-4**
Description	These standards ensure that foam used at sea is fit for purpose and takes into consideration performance with sea water induction and temperature conditioning (accelerated ageing).		For UK offshore helidecks, the standard adopted by the Civil Aviation Authority (CAA) is CAP 437 – Standards for Offshore Helicopter Landing Areas, Chapter 5, paragraph 2.6.	MIL-F-24385 is a US Military Test Specification that critically tests AFFFs for both extinguishment and burnback in sea and potable (fresh) water.	NFPA 11 is an internationally recognised US Standard for Low-, Medium-, and High-Expansion Fire Fighting Foam.				
Sector(s) applicable	Maritime	Maritime	Offshore Helidecks (UK)	Military					
Type(s) of fire / fuel				Heptane fire, Unleaded petrol					
Type(s) of foam									
Area applicable									
Application conditions			Tested in sea water and freeze protected	Using foam with potable and sea water.					
Application Rate (L/min/m2)	2.52	2.52		1.65 or 2.91					
Discharge Rate (L/min) and duration	11.4 (300 sec +/- 2)	11.4 (300 sec +/- 2)		7.57 (90 seconds)					

	International Maritime Organization		CAP 437	Military Specification (US)	National Fire Protection Agency (NFPA)	ISO - 7203			
	IMO MSC.1/Circ.1 312	**IMO MSC Circ.670**	**CAP 437**	**MIL-F-24385**	**NFPA 11**	**7203-1**	**7203-2**	**7203-3**	**7203-4**
Extinguishing time (with flickers)									
Extinguishing time (full)	Depends on class	Depends on class		Depends on pan; <30; <50					
Pre-burn time				10 seconds					
Burnback test (and waiting time)				Yes (25% in 360 seconds); 60s					
20% Re-ignition Time (mins)									
Nozzle type	"Uni 86" Foam Nozzle"	"Uni 86" Foam Nozzle"				"Uni 86" Foam Nozzle"	"Uni 86" Foam Nozzle"	"Uni 86" Foam Nozzle"	"Uni 86" Foam Nozzle"
Nozzle pressure (Kpa)	630 +/- 30	630 +/- 30		680					
Degradation considered				Yes- requires a result of 50% or greater for a BOD/ COD ratio					
Pass/Fail test?									
Frequency of monitoring/ conformity testing									
Sea water or powder compatibility	Sea water (if compatible)	Sea water (if compatible)		Sea water, powder					

Appendix 6
List of alternative fire-fighting foam products available on the EU market, as identified in consultation responses

Product	Manufacturer/Supplier
ECOPOL	Bio-ex
BIO FOR	Bio-ex
BIO FOAM	Bio-ex
BIO T3	Bio-ex
BIO T6	Bio-ex
RE-HEALING™ RF3, 3% Low Viscosity Foam Concentrate	Solberg
PROFOAM 806G	Gepro Group
Sthamex F-15	Dr. Sthamer
Sthamex F-6	Dr. Sthamer
Testschaum V	Dr. Sthamer
Freedol SF	3F
Freedol	3F
Freefor SF	3F
Hyfex SF	3F
Freedex SF	3F
Respondol ATF 3-3	Angus fire
Respondol ATF 3-6	Angus fire
High Combat A	Angus Fire
Jetfoam 1%	Angus fire
Jetfoam 3%	Angus fire
Jetfoam 6%	Angus fire
Syndura	Angus fire
Expandol LT	Angus fire

Product	Manufacturer/Supplier
Expandol	Angus fire
Forexpan	Angus fire
Trainol-3	Angus fire
Trainol-6	Angus fire
TF 3	Angus fire
TF 6	Angus fire
TF 90	Angus fire
Unipol FF 3/6	Auxquimia
TF 136	Auxquimia
EE-3	Auxquimia
SF-60 L	Auxquimia
H-930	Auxquimia
RFC-105	Auxquimia
CAFOAM	Auxquimia
Unipol FF 1	Auxquimia
Class A Plus	Chemguard
Extreme	Chemguard
DeltaFire	DeltaFire
Schaumgeist	Dr. Sthamer
Sthamex F-6	Dr. Sthamer
Sthamex F-15	Dr. Sthamer
Sthamex F-20	Dr. Sthamer
Sthamex F-25	Dr. Sthamer
Sthamex-class A	Dr. Sthamer
Moussol FF 3x6	Dr. Sthamer
Fettex	Dr. Sthamer
Übungsschaummittel-N	Dr. Sthamer
Übungsschaummittel-U	Dr. Sthamer
Sthamex - K	Dr. Sthamer
iFoam	Febbex

Product	Manufacturer/Supplier
Greenagent Technology	Fireade
-	Firechem
-	Foamtech AntiFire
Enviro 3x3 Plus	Fomtec
Enviro 3x3 ultra	Fomtec
Enviro 3 % ICAO	Fomtec
Enviro 3x6 Plus	Fomtec
Enviro 6x6 Plus	Fomtec
Enviro USP	Fomtec
KV-Lite PF	KVFires
KV-Lite HEF	KVFires
KV-Lite HAZMAT Foam	KVFires
KV-Lite Class-K Foam	KVFires
Ecopol	Leader/ BioEx
Ecopol 3x6	Leader/ BioEx
Ecopol 6	Leader/ BioEx
Ecopol F3HC	Leader/ BioEx
Bio T3	Leader/ BioEx
Bio T6	Leader/ BioEx
Bio for C	Leader/ BioEx
Bio for N	Leader/ BioEx
Bio for S	Leader/ BioEx
Bio Foam 5	Leader/ BioEx
Bio Foam 15	Leader/ BioEx
Responder Class A	NationalFoam
Knockdown	NationalFoam
High Expander	NationalFoam
Training Foam	NationalFoam
Bluefoam 3x3	Orchidee
Bluefoam 1x3	Orchidee

Product	Manufacturer/Supplier
Bluefoam 3x6	Orchidee
Bluefoam 6x6	Orchidee
Orchidex ME 1% F-ECO	Orchidee
Orchidex ME 3% F-ECO	Orchidee
Orchidex ME 3% HP	Orchidee
Orchidex ME 3% F-10	Orchidee
Orchidex ME 3% ECO	Orchidee
Orchidex ME 6% F-ECO	Orchidee
Orchidex Training Foam	Orchidee
Orchidex A	Orchidee
Orchidee XF 3000	Orchidee
Re-Healing Foam RF-H+	Solberg
Re-Healing Foam RF1 1%	Solberg
Re-Healing Foam RF1-S 1%	Solberg
Re-Healing Foam RF3 3%	Solberg
Re-Healing Foam RF6 6%1 1	Solberg
Re-Healing Foam RF3x3 FP ATC	Solberg
Re-Healing Foam RF3x6 ATC	Solberg
Re-Healing Foam RF 3x6 FP ATC	Solberg
Re-Healing Foam RF-MB	Solberg
Re-Healing Foam RF6 6% 2	Solberg
Re-Healing TF	Solberg
Aberdeen Foam 1% F3	OilTechnics
Aberdeen Foam 3% F3	OilTechnics
Aberdeen Foam 3x3% AR-F3	OilTechnics
Aberdeen Foam 1% Class A	OilTechnics
Aberdeen Foam 1% Training Foam	OilTechnics
Aberdeen Foam 3% Training Foam	OilTechnics
Silvara 1	vsFocum

Product	Manufacturer/Supplier
Silvara ZFK	vsFocum
Silvara APC 3x3%	vsFocum
Silvara APC 3x6%	vsFocum

Appendix 7
"Pre-Annex XV Dossier"